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MANAGEMENT OF WESTERN HEMLOCK-SITKA SPRUCE FORESTS FOR TIMBER PRODUCTION

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ABSTRACT

Ecological and management information for the coastal western hemlock-Sitka spruce forests is summarized in this report. Topics emphasis include logging methods, silvicultural practices, artificial regeneration, residue disposal, wood quality, growth and yield, and forest protection. Considerations for protection and nontimber values as well as timber management

KEYWORDS: Western hemlock, *Tsuga heterophylla*, Sitka spruce, *Picea sitchensis*, timber management, management practices, regeneration (stand), site preparation, silviculture.

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INTRODUCTION

This report summarizes current knowledge on silviculture of western hemlock-Sitka spruce forests.[1/] The intent is to provide practical information for managing these forests for timber production. Emphasis is on Oregon, Washington, and Alaska more than on British Columbia, although ecologically the type is a continuum; environmental conditions and forest stands gradually vary with latitude. In general, information and silvicultural recommendations for Oregon, Washington, and Alaska apply in British Columbia as well.

THE HEMLOCK-SPRUCE TYPE

The hemlock-spruce type as defined here occupies a narrow 2,000-mi-(3 200-km-) long band along the Pacific coast from near Coos Bay, Oregon, to Prince William Sound, Alaska (fig. 1). Through most of this

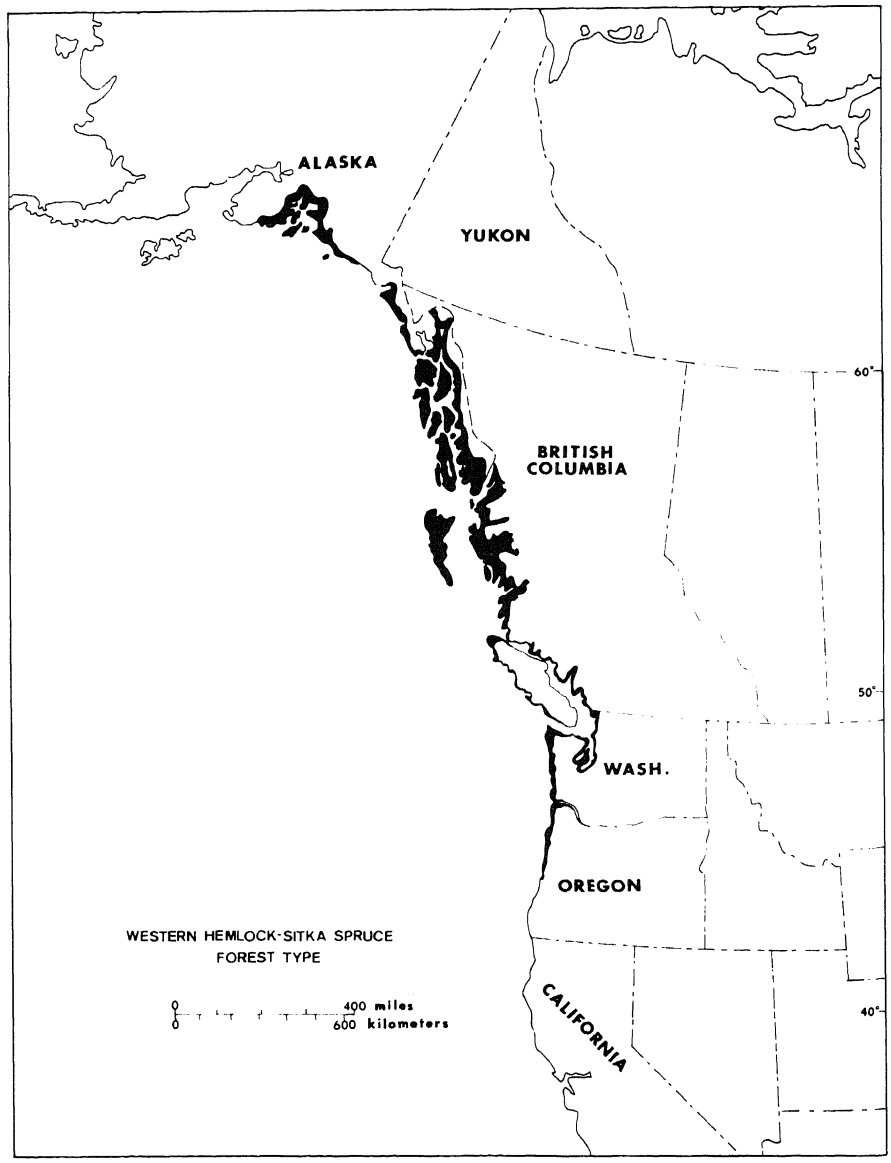

Figure 1.--Approximate range of the western hemlock-Sitka spruce forest type where mixtures of western hemlock and Sitka spruce occur in commercial forest stands.

1/ Common and scientific names of plants are listed in the appendix.

distance, the type is roughly defined by the commercial range of Sitka spruce. Toward the south, hemlock extends farther inland and merges with Douglas-fir. At the northwestern extreme, the hemlock-spruce type is defined roughly by the range of western hemlock. Pure stands of Sitka spruce extend farther west to Afognak and Kodiak Islands. Spruce prefers a cool, moist, maritime climate without pronounced summer drought. These conditions are characteristic of the coastal fog belt and identify the forest environment under consideration here. Transit from hemlock-spruce to pure hemlock in Oregon and Washington and to pure spruce in Alaska often are gradual, and much of the information presented here is applicable in these areas.

In Alaska the hemlock-spruce type is well defined. A series of icefields and high mountain passes above timberline form a distinct separation between the moist coastal forests and the dry white spruce-hardwood forests of interior Alaska and the white spruce-fir-hemlock forests of interior British Columbia. The type reaches its greatest extent in southeast Alaska. Here it extends from sea level to timberline on the offshore islands and on the mainland, covering a width of some 130 mi (210 km). Timberline may extend to 3,500 ft (1 000 m); occasional trees are found to 3,900 ft (1 200 m). Timberline is influenced locally by wind, aspect, snow accumulation, and avalanching. On the mainland the type extends inland several miles along fjords and inlets. Inland penetration is restricted to a few locations along the major rivers such as the Stikine and Taku, and at the head of Lynn Canal.

Farther northwestward along the Gulf of Alaska, the hemlock-spruce type narrows greatly, limited by steep mountains and piedmont glaciers edging the sea. Within Prince William Sound, the type again widens to some 60 mi (90 km), including the islands and a narrow mainland strip. Timberline lowers toward the northwest, occurring at 1,000 to 1,500 ft (300 to 450 m) on the Kenai Peninsula.

West of Prince William Sound, western hemlock is replaced by mountain hemlock along the southern tip of the Kenai Peninsula, and Sitka spruce becomes the predominant species. On the Kodiak-Afognak archipelago Sitka spruce is the only conifer present. Here it is expanding its range into a tundra-grassland complex at the rate of about 1 mi (1.6 km) per century (Griggs 1934, 1937). For management purposes then, the northwestern limit of the western hemlock-Sitka spruce type lies within Prince William Sound.

South of Alaska the hemlock-spruce type is less well defined. Within British Columbia, the Queen Charlotte Islands lie entirely within the type; along the northern mainland from Portland Canal south to Vancouver Island the type extends inland several miles along fjords and channels. Farthest inland penetration is along the Skeena River Valley where coastal hemlock-spruce first merges with western hemlock which grades into interior forest types.

On Vancouver Island the hemlock-spruce type is prominent on the low-lying northern tip north and west of Holberg. Farther south, it is restricted to a narrow strip along the west coast with stringers extending inland along major streams (Packee 1974a, 1974b). Eastward on Vancouver Island and along the adjacent mainland, the type grades

into hemlock or hemlock-fir in response to drier climatic conditions. Here Sitka spruce is relegated to river bottoms and moist upland sites near tidewater.

In Washington, the most extensive area of the hemlock-spruce type is on the lower elevations of the Olympic Peninsula with stringers extending inland along major streams. Occasionally it reaches 3,000 ft (900 m) in elevation in especially moist situations in the Olympic Mountains. Farther south, the type narrows, occupying the coastal strip and lower elevations, grading into the hemlock type as drier conditions prevail (Juday 1976). Midway along the Oregon coast, the type may reach elevations of 1,500 to 1,800 ft (450 to 550 m) within 6 mi (10 km) of tidewater and would undoubtedly reach higher if topography permitted (fig. 2). However, higher elevations for the most part lie too far inland, where dry summer conditions are unmodified by frequent summer fog. In many areas the type may extend inland for 6 mi (10 km) or more, and along streams or rivers it may extend inland for 20 mi (30 km). From the standpoint of management, the type becomes insignificant south of Coos County, Oregon; although in southern Oregon and northern California, it is found intermittently, confined to seaward slopes and certain north-facing slopes and valley bottoms.

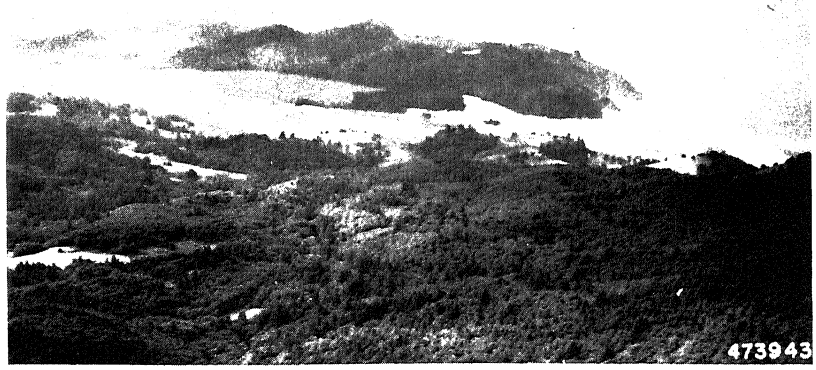

Figure 2.--Along the Oregon coast the hemlock-spruce type occurs at low elevations near the sea. The stand in foreground originated after a fire and includes a high percentage of red alder. Salmon River estuary, Cascade Head Scenic-Research Area, Oregon.

CLIMATE

The hemlock-spruce type is confined to an area of maritime climate with abundant moisture throughout the year, relatively mild winter

temperatures, and cool summers. Lack of a pronounced summer drought i perhaps the most important factor affecting vegetation. The combinati of warm water from the Japan Current offshore and prevailing westerly onshore winds result in cool, humid conditions throughout the type.

Precipitation accompanies cyclonic, low pressure systems that approach from the sea, carried by the prevailing westerlies. From abo mid-May to mid-September an extensive high pressure area dominates the weather along the Pacific coast off Oregon, Washington, and southern British Columbia, diverting storm tracks northward toward the Gulf of Alaska, where the low pressure systems become semipermanent. As a result, summer precipitation tends to be greater toward the north. Along the southern Alaska coast frequent light summer drizzle is the rule, with occasional fog along the outer coast. At Cordova, Alaska, the average during June to September, a trace or more of precipitation occurs during 22 to 24 days of each month (table 1).

Table 1--Mean annual and selected monthly data for representative stations within the hemlock-spruce type, 1950-74

Station	Latitude, N.	Longitude, W.	Degree-days[1/]	Precipitation	July precipitation	Days per month with trace or more of precipitation				Snowfall	Frostfree days
						June	July	August	September		
				cm	cm					cm	
Brookings, Oregon	42°03'	124°17'	2 511	204.9	0.4	9	6	7	8	1	294
Otis, Oregon	45°02'	123°56'	2 131	250.2	2.8	15	8	9	12	13	192
Forks, Washington	47°57'	124°22'	1 942	297.8	5.4	14	9	12	12	43	190
Quatsino, B.C.	50°32'	127°37	1 697	235.2	4.4	10	10	13	15	58	200
Langara, B.C.	54°15'	133°03'	1 204	165.5	7.4	19	20	20	22	71	241
Annette, Alaska	55°02'	131°34'	1 408	298.0	13.1	20	19	20	21	142	210
Sitka, Alaska	57°04'	135°21'	1 221	214.4	11.7	20	19	21	24	114	196
Juneau, Alaska	58°22'	134°35'	1 014	134.5	10.7	21	21	22	23	279	129
Cordova, Alaska	60°30'	145°30'	851	226.6	17.5	22	24	23	22	340	111
Seward, Alaska	60°07'	149°27'	989	151.4	7.2	16	16	19	20	221	153

[1/] Base: 5°C.

Toward the southern part of the hemlock-spruce type, precipitatio is less frequent during the summer. For example, at Otis, Oregon, a trace or more of precipitation occurs from 8 to 15 days per month duri July to September. During these months fog and moist maritime air apparently play a particularly important role in maintaining moist conditions necessary for the hemlock-spruce type. During the summer f commonly forms, covering coastal lowlands and following river drainage The extent of fog penetration depends on heat loss to the atmosphere a night. During cloudy weather, air temperatures over land and sea are relatively equal. During clear weather, however, heat loss from the land is greater and with offshore wind fog may penetrate for 20 mi (30 km) up the longer drainages. As daytime temperatures rise fog is dissipated, often by midmorning in interior areas. It may remain

throughout the day along the coast. Fog collects on tree crowns and drips to the ground, adding as much as 25 percent to the total precipitation reaching the ground (Isaac 1946). This "fog drip" is an important factor in reducing fire danger and providing soil moisture during the growing season. In addition, moisture-laden air results in reduced transpiration, which helps trees to conserve moisture.

Total annual precipitation tends to be high throughout the type, apparently little influenced by latitude (table 1). The high mountains bordering the sea, narrow fjords leading inland, and other local topography greatly influence total precipitation. For example, the Juneau Airport, situated on a glacial flat in the lee of 3,000-ft (900-m) mountains, receives 53 in (135 cm) of precipitation annually; 9 miles (15 km) away the city of Juneau, located on the windward slope of a narrow fjordlike channel, receives 92 in (234 cm).

Depth of snowfall during the winter decreases southward. Based on snowfall records over a 25-year period, average depth of annual snowfall is 134 in (340 cm) at Cordova, Alaska, compared with 23 in (58 cm) at Quatsino, British Columbia; 5 in (13 cm) at Otis, Oregon; and 0.5 in (1 cm) at Brookings, Oregon (table 1).

Summer temperatures within the hemlock-spruce type tend to be cool and equable, lacking the extremes found within many other forest types. Length of growing season and total solar energy received during the growing season vary considerably over the 19° of latitude spanned by the type. Cumulative growing degree-days[2/] during the growing season range from 4 520°F-days (2 511°C-days) at Brookings, Oregon, to 1 532°F-days (851°C-days) at Cordova, Alaska (table 1 and unpublished data on file at Forestry Sciences Laboratory, Juneau, Alaska). This wide range of temperatures during the growing season accounts for much of the variation in productivity, soil development, and species composition within the type.

GEOLOGY AND SOILS

The physiography, geomorphology, and major geological features for various portions of the hemlock-spruce type have been described for Oregon (Baldwin 1964); Washington (Campbell 1962); British Columbia (Holland 1964); and Alaska (Reed 1958, Miller 1958). In addition, the major physiographic events of the late pleistocene have been summarized by Heusser (1960).

On the Olympic peninsula in Washington and southward into Oregon, soils have developed from basalts, sandstone, tuffs, and breccias. Unconsolidated deposits of sand, silt, and gravel occur along most streams. Glacial till or outwash is locally evident on the Olympic Peninsula; the southern extent of pleistocene glaciation is located about 6 mi (10 m) south of the Ozette River (Arnold 1906).

Northward in British Columbia and Alaska, glaciation has been an important factor in shaping the landscape and in the distribution of soil parent material. Most valleys tend to be U-shaped as a result of glaciation. Glacial till of varying thickness covers much of the valley bottoms and extends far up the sideslopes.

[2/] Growing degree-days are based on average daily temperature above a threshold temperature of 41°F (5°C).

In southeast Alaska, most exposed rock is of paleozoic age, with large areas of granitic, metamorphic, and volcanic rock. Metamorphic rocks are intruded with dikes, sills, stocks, and small batholithic masses. Granitic rocks (mostly granodiorite) form the bulk of the larger mountain systems. Extensive areas of limestone occur in some areas (Buddington and Chapin 1929).

Soils vary by latitude within the hemlock-spruce type. In the Coast Ranges of Oregon and Washington, inceptisols and ultisols are the most widespread soils; on the Olympic Peninsula, inceptisols are the most common. Spodosols are less abundant (Franklin and Dyrness 1973, Heilman 1976). On Vancouver Island, British Columbia, spodosols and inceptisols are common over most of the island. Toward the northern portion of the island on the western coastal plains, histosols are common (Keser and St. Pierre 1973). In Alaska, spodosols and histosols are the most common soils (Sheehy 1975, Gass et al. 1967). Throughout the type, entisols are found along streams. In southeast Alaska, all mature soils under timber have strongly developed spodic horizons (Stephens 1969a).

In general, soils tend to be less well developed northward. In Alaska very immature soils are found in locations that have undergone recent glacial recession (Chandler 1942, Crocker and Dickson 1957, Ugolini 1966).

Research on forest soils has been carried on for many years in the Pacific Northwest, although most has been done outside the hemlock-spruce type (Tarrant 1964b, Klock 1969). Detailed comparison of soil characteristics within the hemlock-spruce type has not been made, although such a comparison would certainly be of value to the land manager in determining the applicability of published research results throughout the type. Existing information suggests that differences in soil properties at widely divergent points are great. For example, in comparing soils on the Alsea drainage in Oregon with soils in southeast Alaska, Stephens (1966) found the average depth of surface organic matter to be five times greater in Alaska; clay content three times lower.

In Alaska most spodosols have low clay content. Collodial organic and iron compounds are the main source of cation exchange capacity and water retention in these soils (Stephens 1969, Holty and Heilman 1971). They have relatively high moisture retention ability and relatively high rates of water transmission (Patric and Swanston 1968). Thixotropic properties of some horizons make these soils unstable and unsuitable for many engineering purposes (Bishop and Stevens 1964, Stephens 1966).

Despite their diverse parent material, spodosols in Alaska have similar chemical properties in their upper horizons. Influence of parent materials on chemical properties of soils formed on basalt and limestone are evident only in the lowest horizons (Heilman and Gass 1974). A substantial proportion of nutrients are in the soil organic layers; even in the deeper soils of southeast Alaska, tree rooting is generally shallow. Ten inches of mineral soil over bedrock appears to be sufficient depth for maximum tree production and site class (Heilman and Gass 1974). Destruction of the upper soil layers is therefore likely to have adverse effects on tree growth.

In summary, it appears that toward the south soils tend to be deeper, better developed, and more fertile at greater depth than soils toward the north. From the standpoint of tree establishment and growth, surface organic material and upper soil horizons take on added importance northward. Recommendations in the literature for seed bed suitability which involve "mineral soil" should be evaluated carefully; they may not be applicable beyond the area in which studies were conducted. The same is true about engineering properties of soils, and practices that are recommended for use in one location may prove to be totally unsuitable in other areas. A detailed comparison of soil characteristics throughout the hemlock-spruce type would be of great value for the practitioner faced with the prospect of managing diverse soils within the type.

VEGETATION

Classification

Major habitats within the hemlock-spruce type have been generally described, but a comprehensive vegetation classification system for the type as a whole has not been developed. Limited analyses of plant communities have been made in parts of Oregon and Washington (Hines 1971, Meurisse and Youngberg 1971, Sharpe 1956, Fonda 1967, Franklin and Dyrness 1973). In British Columbia, Krajina (1965, 1969) and Packee (1974a, 1974b) have described ecological forest units. In Alaska, major vegetative types have been described in general terms[3/] (Dachnowski-Stokes 1941, Neiland 1971, Taylor 1932). A thorough analysis of plant communities has been made of only one area on the Alaska coast (Worley 1977).

Forests dominate the landscape throughout the hemlock-spruce type. Most commercial forest communities occur on relatively moist, well-drained habitats with well-developed soils. These habitats cover a range of soil and moisture conditions as well as climatic differences.

Naturally occurring nonforest habitats are confined primarily to the ocean front in Oregon and Washington where Franklin and Dyrness (1973) recognized sand dune and strand communities, tideland communities, and herb and shrub-dominated communities. Tide-influenced communities are also found in British Columbia and have been described for Alaska (Stephens and Billings 1967, Worley 1977).

Nonforest alpine communities become common northward as the hemlock-spruce type widens and timberlines lower. Worley (1977) described an alpine community in Alaska.

Other interesting habitats may be partially or completely forested. In Alaska deciduous shrublands, peatland, spruce parkland, and beach communities have been described (Worley 1977), as well as a forest community growing on a thin mantle of till on an active glacier (Stephens 1969b).

In British Columbia, a narrow band along the outer coast has been described in which Sitka spruce forms nearly pure stands, having replaced western hemlock and western redcedar because of tolerance to salt spray (Cordes 1972).

[3/] Palmer, L. J. 1942. Major vegetative types of southeastern Alaska. U.S. Dep. Inter. Fish and Wildl. Serv., Juneau, Alaska. 16 p.

In Oregon and Washington, Franklin and Dyrness (1973) described forested swamps, in which western redcedar or red alder are dominant, along with western white pine, shore pine, Sitka spruce, and western hemlock. Understory tends to be rank, with dense shrub layers.

In Alaska, muskegs consisting of deep layers of peat are common (Dachnowski-Stokes 1941, Neiland 1971, Worley 1977). They support sparse stands of shore pine, Sitka spruce, mountain hemlock, Alaska-cedar, and western redcedar (fig. 3). Poorly drained organic soils supporting noncommercial forest stands of western redcedar, Alaska-cedar, mountain and western hemlock, and Sitka spruce are also common throughout coastal Alaska. Although important from the standpoint of watershed protection, wildlife habitat, and other uses, these sites are not now important for timber production.

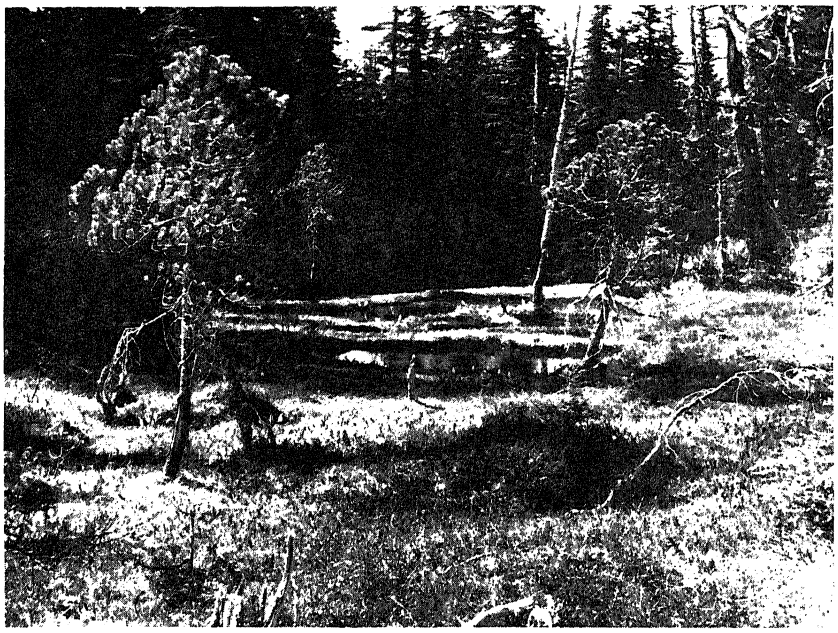

Figure 3.--Shore pine growing on a muskeg or sphagnum bog, Chicagof Island, Alaska.

Forest Composition

The hemlock-spruce type includes some of the finest forests in North America. Old-growth stands contain many extremely large trees, some more than 16 ft (4.9 m) in diameter and over 200 ft (70 m) tall. Productivity of the better sites, as measured by annual biomass or wood production, is among the highest in the world (Briegleb 1940, Fujimori 1971, Munger 1946) (fig. 4). Associated with western hemlock and Sitka spruce in portions of the type are Douglas-fir, western redcedar, and 11 other conifers. There are eight broadleaf trees; black cottonwood, red alder, and bigleaf maple are the most important. Broadleaf trees, however, are far less common than in many forest types.

A number of excellent references are available for identification of trees, shrubs, and other vegetation within the hemlock-spruce type. For the Pacific Northwest area, the five-volume "Vascular plants of the Pacific Northwest" (Hitchcock et al. 1955, 1959, 1961, 1964, 1969) is

Figure 4.--A 160-year-old, even-aged stand of hemlock and spruce on Tuxekan Island, Alaska. Even-aged stands such as this contain prime sawtimber and are far less defective than older, uneven-aged stands.

one of the most complete and detailed. For British Columbia, Hosie's (1969) "Native trees of Canada" provides good coverage of tree species. Calder and Taylor's (1968) "Flora of the Queen Charlotte Islands" covers vascular plants of that interesting archipelago.

The most extensive published flora for use in Alaska, "Flora of Alaska and Neighboring Territories" (Hultén 1968), includes keys and descriptions for all vascular plants known in the area. For trees and shrubs, "Alaska Trees and Shrubs" (Viereck and Little 1972) is an excellent reference. A condensed version for pocket use is also available (Viereck and Little 1974).

The most comprehensive single source of information on the silvical characteristics of the tree species within the entire range of hemlock-spruce forests is "Silvics of Forest Trees of the United States" (Fowells 1965). Range maps for all the major tree species within the hemlock-spruce type are shown in this reference. In addition, more recent maps can be found in the "Atlas of United States Trees" (Little 1971, Viereck and Little 1975). For nomenclature of trees we have followed Little (1953a).

Tree species occur in various combinations as a result of many overlapping natural ranges (fig. 5). Within their natural ranges,

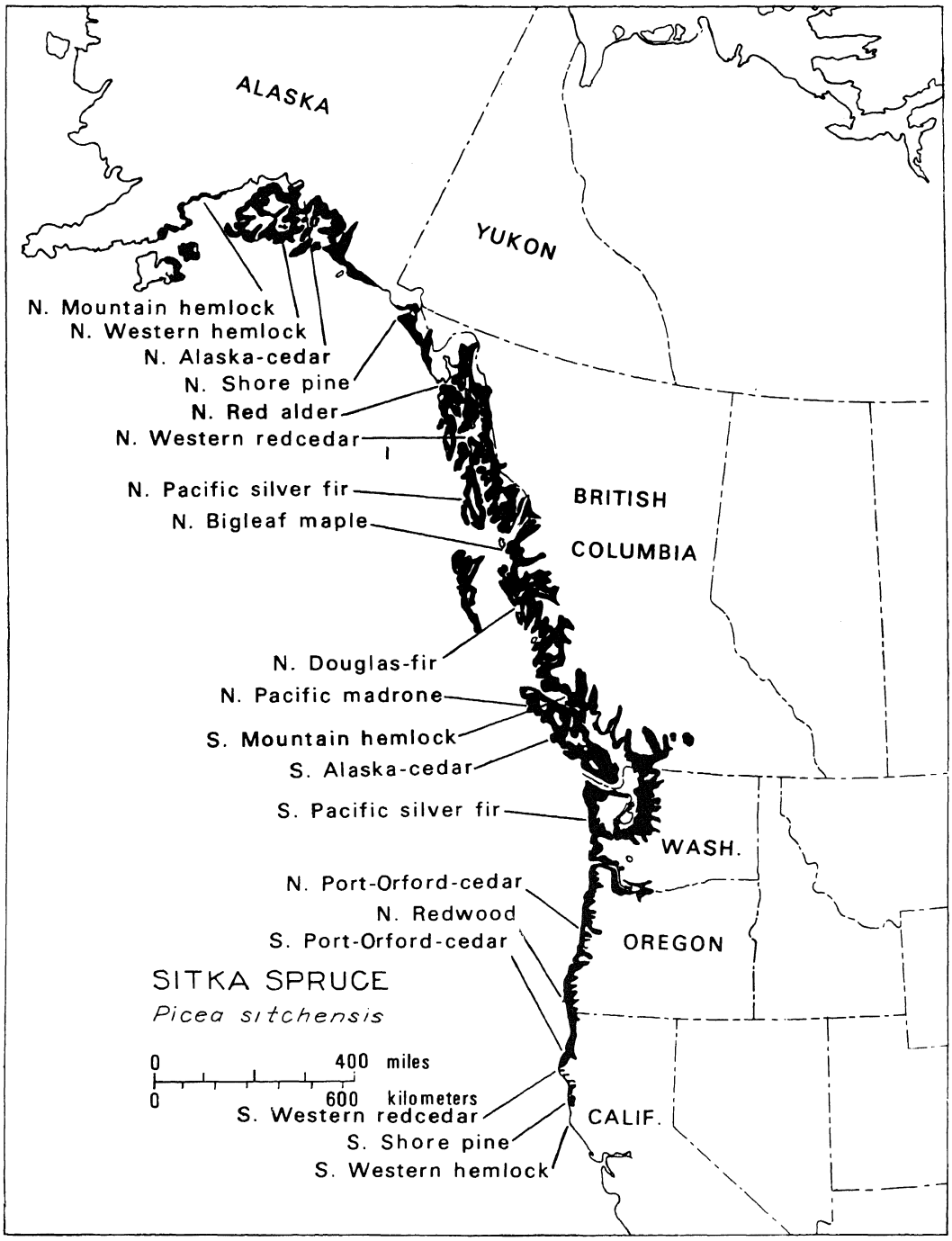

Figure 5.--The Pacific coastal strip showing the range of Sitka spruce and, within it, the approximate range of associated tree species. N and S indicate approximate north and south limits of range.

habitat conditions, history of stand establishment, and successional stage influence forest composition. The tendency within the type for drier, warmer conditions toward the south and east and cooler, wetter conditions toward the north and west helps to explain much of the variation in species composition.

Pacific silver fir becomes an associate north of the Columbia River and extending north through British Columbia. It has a limited range in Alaska, rarely exceeding 1,000 ft (300 m) in elevation. Western redcedar is an important associate at low elevation to 56° latitude where its northern progress is thought to be limited by temperature during the growing season (Gregory 1957b). Alaska-cedar and mountain hemlock occur at elevations well above hemlock-spruce in Oregon and Washington; but with increasing latitude, they occur at lower elevations and become associates of western hemlock and Sitka spruce near the center and northern tip of Vancouver Island. Shore pine is confined mainly to maturing coastal sand dunes in Oregon and Washington but in Alaska may occur up to 1,500-ft (450-m) elevation. It extends north as far as Yakutat. Sitka spruce, which in Oregon and Washington rarely has the opportunity to grow at higher elevations because of low topography along the coast and summer drought farther inland, is found in Alaska on nunataks as high as 4,000 ft (1 200 m) (Heusser 1954).

Toward the western portion of Prince William Sound, mountain hemlock along with Sitka spruce are the most prominent species. Alaska-cedar extends along the coast to Port Wells in Prince William Sound, but other associates drop out along the way. Of all tree species within the hemlock-spruce type, Sitka spruce occupies the most extensive range within Alaska.

The natural ranges of trees within the hemlock-spruce type reflect the interaction of climate and the requirements of the species. For example, hemlock-spruce merges into the Douglas-fir type in areas having a history of pronounced summer drought. Usually there is a narrow transition zone supporting all three species. Within the type, the range of Douglas-fir extends northward only to Gardner Inlet on the British Columbia mainland. Although the species is capable of growing in Alaska (Harris 1971b), its natural range appears to be restricted because of lack of a pronounced fire history farther north (Schmidt 1960).

Another factor affecting tree ranges is the length of time since deglaciation. Movement of tree species as a result of climatic changes is well documented (Heusser 1960, Hultén 1937). Examples can be found with northerly expansion of Pacific silver fir in southeast Alaska (Schmidt 1957, Heusser 1960) and southwesterly expansion of Sitka spruce on Kodiak Island southwestward of the hemlock-spruce type (Griggs 1934). Mountain hemlock and western hemlock also may be moving southwestward in Alaska, but this is not documented.

Understory Vegetation

Young hemlock-spruce forests are typically dense, gradually opening up with age to allow development of a lush understory of shrubs, herbs, grasses, and cryptogams. In open old-growth stands, understory vegetation may be tall and so dense that travel through the forest can be difficult. Species diversity, size, and growth rate of understory plants generally are highest in Oregon and Washington, gradually decreasing northward.

In Oregon and Washington on sites modal in environmental conditions, common understory species in hemlock-spruce forest include *Polystichum munitum*, *Oxalis oregana*, *Maianthemum dilatatum*, *Montia sibirica*, *Tiarella trifoliata*, *Viola sempervirens*, *V. glabella*, *Disporum smithii*, *Vaccinium parvifolium*, and *Menziesia ferruginea*.

On less favorable sites, *Gaultheria shallon*, *Rhododendron macrophyllum*, and *Vaccinium ovatum* are common. On wetter forest sites, the previously mentioned modal species occur, along with *Athyrium filix-femina*, *Blechnum spicant*, *Dryopteris austriaca*, and *Sambucus callicarpa* (Franklin and Dyrness 1973).

In Alaska the more common understory plants include *Oplopanax horridus*, *Vaccinium ovalifolium*, *V. parvifolium*, *V. alaskaense*, *Menziesia ferruginea*, *Rubus spectabilis*, *R. pedatus*, *R. parviflorus*, *Cornus canadensis*, *Dryopteris dilatata*, *Ribes bracteosum*, *R. laxiflorum*, and *Streptopus amplexifolius*.

Cryptogams are extremely abundant throughout the hemlock-spruce type. The Olympic Peninsula is especially noted for mosses, many of which occur as epiphytes on living trees (Pechanec and Franklin 1968, Coleman et al. 1956). Detailed taxonomic and ecological studies have been made on the Olympic Peninsula (Sharpe 1956, Coleman et al. 1956, Harthill 1964). Information on the distribution of cryptogams is also available for the hemlock-spruce type in Alaska (Worley 1970a, 1970b).

Understory vegetation is important for wildlife and for the functioning of the forest ecosystem. Larger plants, such as shrubs, tall ferns, and herbs, often compete directly with tree seedlings for light and growing space. When stands are opened by timber harvest, understory plant species may proliferate and capture the site. Hines (1971) noted that 12 species of shrubs occurred on two plant communities dominated by hemlock-spruce overstory in Oregon (table 2). Several of these, along with tall herbaceous plants and ferns, are important competitors of conifers.

Table 2--A summary of the percentage of plots with shrub species present within two hemlock-spruce communities in Oregon (Hines 1971)

Shrub species	Plant community	
	Hemlock-spruce/ devilsclub-lady fern	Hemlock-spruce/ salal-deerfern
	Percent	
Vaccinium parvifolium	90	100
Menziesia ferruginea	71	90
Berberis nervosa	5	0
Acer circinatum	57	0
Oplopanax horridus	52	0
Gaultheria shallon	19	100
Vaccinium ovalifolium	90	71
Rubus spectabilis	62	48
Rubus nivalis	0	5
Sambucus callicarpa	0	5
Rubus parviflorus	5	0
Vaccinium ovatum	0	19

Forest Succession

Within the hemlock-spruce type, forest succession follows disturbances, such as logging, fire, blowdown, insect attack, landslide, glacial retreat, or uplift from the sea.

Primary forest succession occurs after new exposure of barren land; for example, by glacial retreat, uplift from the sea, formation of stream bars, or landslide. Initially, little or no vegetation or organic matter is present. Soil is poorly developed and may lack a faunal population.

Secondary forest succession follows disruption of an existing forest community rather than by exposure of new land. Blowdown, fire, and logging are the most common causes of disturbance. Disturbance is less drastic than with primary succession; and components of the former stand (such as live seeds, roots, or entire plants) remain, along with accumulated organic matter. Soil may be well developed and may contain a large and diverse faunal population.

In Alaska, studies of forest succession have emphasized primary succession because the widespread and rapid retreat of glaciers during the last 200 years has provided numerous opportunities for study (fig. 6).

Figure 6.--Primary forest succession following glacial retreat is common within the hemlock-spruce type in coastal Alaska. Mendenhall Glacier, Alaska.

In Oregon and Washington, opportunities for study of primary succession are largely confined to stream terraces; most studies stress secondary succession. The successional trend after blowdown, fire, or logging on commercial forest land on upland sites tends toward replacement of forbs, shrubs, or alder with appropriate mixtures of Sitka spruce, western hemlock, Douglas-fir, or cedars, depending on latitude, followed by eventual replacement with western hemlock.

Tree species differ in their requirements for moisture, light, nutrients, heat, and growing space and thereby respond differently to the local environment. For example, lodgepole pine, Douglas-fir, and red alder roots can grow in dense soils that prohibit growth of Sitka spruce, western redcedar, and western hemlock. Pacific silver fir ranks between these two groups (Minore 1969a). Red alder, western redcedar, Sitka spruce, and western hemlock are more tolerant of shallow water tables than Douglas-fir is (Minore 1970, Minore and Smith 1971). Ranked according to flood tolerance, western redcedar and lodgepole pine are most tolerant; red alder, Sitka spruce, and western hemlock are intermediately tolerant; and Douglas-fir is extremely intolerant (Minore 1968).

Tolerance to salt is important for coastal species, and Sitka spruce is much more tolerant of ocean spray than either western hemlo or western redcedar (Cordes 1972). This accounts for the prominent position of spruce on exposed headlands and beaches along the outer coast. In Alaska, spruce is a pioneer species on recently uplifted beaches.

Initial establishment of species depends on seed source, seed be soil, moisture, and other factors. In Oregon and Washington, Frankli and Dyrness (1973) recognized two major kinds of seral forest stands the hemlock-spruce type: (1) coniferous, containing varying mixtures spruce, hemlock, and Douglas-fir; and (2) red alder or other hardwood These two distinctive stand types usually occur as a result of site disturbance and seed source. In general, more severe soil disturbanc tends to result in earlier successional status of the new stand. Sli disturbance favors establishment of hemlock, and intermediate disturb favors establishment of Sitka spruce or Douglas-fir. Severe soil dis turbance from logging or fire sets the stage for alder establishment, and if a seed source is available, alder will often capture the site.

In Oregon and Washington, alder is concentrated on mesic sites w a history of scarification or fire (Newton et al. 1968). In Alaska, becomes established on disturbed soil where the duff layer has been removed by logging (Harris and Farr 1974), and on alluvial and colluv soils lacking a well-developed duff layer.

Throughout most of the hemlock-spruce type, a dense understory o salmonberry may become established beneath alder. Hemlock seldom inv these sites. Sitka spruce will become established but often with gre difficulty. If alder is removed, salmonberry tends to replace it and further retard conifer development. Under drier soil conditions, Sit spruce will become established with the alder, and later, western hemlock; these remain suppressed but gradually overtop and shade out the alder, usually within 40 to 60 years.

In Oregon, toward the southern portion of the hemlock-spruce typ winters are mild and plant growth may continue throughout the year. Here red alder, salmonberry, thimbleberry, vine maple, and large annu plants apparently attain maximum development and play an especially important role in early succession. Dense alder, salmonberry, and thimbleberry are often already established on upland sites, especiall where conifer stands have been opened by wind or from other causes. After removal of the overstory, these species proliferate where they already established and quickly invade disturbed sites. Left untreat they dominate the site for many years. Douglas-fir appears to be incapable of long suppression beneath alder and is only able to becom established in openings where it develops concurrently with the alder (Newton et al. 1968).

Toward the north on sites where disturbance is less or where an alder seed source is not present, mixed stands of Sitka spruce and western hemlock become established along with other conifers. For th first few years, shrubs--such as blueberry, huckleberry, rusty menzie elderberry, and thimbleberry--dominate the site. These shrubs resprou from well-developed root systems or grow from seed and at first, grow much faster than conifers. Within a few years, some conifers usually gain dominance but the stand may be poorly stocked and of poor qualit

Tolerance to shade is especially important for establishment of tree species and in determining successional trends. The most tolera

species becomes established beneath an existing stand and usually becomes the climax species.

Western hemlock is more tolerant of shade than Sitka spruce and dominates reproduction in old-growth forests in Oregon and Washington (Franklin and Dyrness 1973), British Columbia (Krajina 1969), and Alaska (Taylor 1932). The tolerance of a species tends to vary with the climatic conditions in which it grows. For a given species, shade tolerance decreases under cooler, wetter conditions and increases under warmer, drier conditions (Krajina 1965). Thus, within the hemlock-spruce type, tolerance tends to decrease northward. For example, Sitka spruce is considered a tolerant species in Oregon and Washington (Franklin and Dyrness 1973) but intolerant in Alaska (Heusser 1960). Likewise, western redcedar, described as tolerant in Oregon and Washington, behaves as an intolerant species in British Columbia (Schmidt 1955) and in Alaska (Gregory 1957b).

Shade tolerance of the major species in Oregon and Washington compared with those in Alaska (table 3) suggests that tolerance of various species may be affected to different degrees under climatic conditions at the extremes of the hemlock-spruce type--some species remaining unchanged, some moving one level, and some moving two levels. It is difficult to tell how much of these differences results from an inadequate method of describing tolerance and how much from actual differences in tolerance.

Table 3--Tolerance to shade of major tree species by location within the hemlock-spruce type

Area	Very tolerant	Tolerant	Intermediate	Intolerant
Oregon and Washington[1/]	*Abies amabilis* *Tsuga heterophylla*	*Abies lasiocarpa* *Chamaecyparis lawsoniana* *Chamaecyparis nootkatensis* *Picea sitchensis* *Sequoia sempervirens* *Thuja plicata* *Tsuga mertensiana* *Acer macrophyllum*		*Pinus contorta* *Pinus monticola* *Pseudotsuga menziesii* *Alnus rubra*
Alaska[2/]	*Abies amabilis* *Tsuga heterophylla*	*Abies lasiocarpa* *Tsuga mertensiana*	*Picea sitchensis*	*Pinus contorta* *Alnus rubra* *Chamaecyparis nootkatensis* *Thuja plicata*

1/ From Franklin and Dyrness (1973), table 3.
2/ From Gregory (1957b), Schmidt (1955), Heusser (1960); and observations on file at Forestry Sciences Laboratory, Juneau, Alaska.

Alluvial stream terrace sites on entisols in glaciated valleys should be considered separately for purposes of management and general ecological interest. These stream bottomland sites are common throughout the hemlock-spruce type; although plant communities differ by latitude, many of the basic characteristics remain the same.

Best development of these sites is found on the Olympic Peninsula where relatively large seaward-facing valleys, abundant precipitation, and warm but equable summer temperatures combine to produce what has been popularly called the Olympic Rain Forest (Kirk 1966). These old-growth forests are dominated by Sitka spruce and western hemlock

and found in a few major river valleys (Hoh, Quinault, Queets, and possibly Bogachiel Rivers). Trees are very large; dominant spruce reach 90 to 130 in (230 to 330 cm) in diameter and over 250 ft (75 m) in height.

Among the distinctive features of these forests, as pointed out by Franklin and Dyrness (1973), are: (1) an abundance of bigleaf maple and vine maple, (2) a conspicuous coverage by epiphytes, (3) abundant nurse logs, and (4) heavy use by Roosevelt elk. The forests are located within the floodway zone of streams. As classified by Bauer (1971), this zone is characterized by braided channels with islands, meanders with point bars, and active processes of erosion and accretion. Gradient varies between 5 and 25 ft per mile (0.9 and 4.7 m/km).

Although these forests are sometimes considered unique to the Olympic Peninsula (Kirk 1966, Sharpe 1956), they are probably best described as variants of what we consider here the hemlock-spruce type (Franklin and Dyrness 1973, Fonda 1974). Western hemlock appears to be the climax species (Fonda 1974), although Sitka spruce behaves as a climax in many ways (Franklin and Dyrness 1973). Feeding by elk on some understory plants, such as salmonberry and elderberry (Sharpe 1956), may be responsible for some unique characteristics of these stream-terrace sites on the Olympic Peninsula. Northward, elk are not present.

Primary forest succession begins on river bars with willows and alder, with dense salmonberry in areas of high soil moisture. This stage gives way later to black cottonwood-Sitka spruce-alder stands. Toward the south, bigleaf maple is an important species, especially on shallow, stony soil. Toward the north, bigleaf maple is lacking but Sitka alder becomes common. Willows and cottonwood are confined largely to mainland valleys. With few exceptions, these species are rarely found on the northern islands.

Early successional stages give way to a Sitka spruce-western hemlock stage as alders, maple, and cottonwood become overtopped. Stands are often open, with dense salmonberry capturing moister areas. Given enough time, western hemlock will come to dominate the site as soils mature. With active stream cutting and meandering, many valley bottom sites may remain in a subclimax successional stage.

Care should be taken with management of alluvial bottom-land sites. Conifer regeneration may be difficult to obtain, as the sites are readily captured by alder and salmonberry and special effort will usually be required to obtain adequate restocking.

Tree Species

In the following pages we look briefly at the major tree species and their ranges, occurrence, and uses. Silvical characteristics of the various species will be discussed further as appropriate.

Western Hemlock

Western hemlock grows along the Pacific coast from northern California to Prince William Sound, Alaska, and is the major species within the hemlock-spruce type (fig. 7). It occurs in dense stands in mixture with Sitka spruce, mountain hemlock, cedars, and other conifers. Tree associates and growth characteristics vary with latitude, soil type, topography, elevation, and stand history.

Figure 7.--Old-growth western hemlock tree near Juneau, Alaska.

In Alaska western hemlock is a major stand component on low-site organic soils and is found in stunted or decumbent form on muskegs. At high elevations, it is mainly replaced by mountain hemlock but is often found at timberline. Best development and growth are on well-drained soils in valley bottoms and on lower slopes where it is an important commercial timber resource.

In southeast Alaska, western hemlock comprises 64 percent of the total growing stock volume (Hutchison 1967). Because figures are not compiled by forest type in the Pacific Northwest or British Columbia, a similar comparison cannot be made for those areas.

Until fairly recently, western hemlock was far less valuable than Douglas-fir or Sitka spruce. Now, however, it is becoming more valuable and interest in management is increasing. In Oregon, Washington, and British Columbia, it is used primarily for construction lumber and pulp. In Alaska, its main use is for dissolving pulp, but more of the better quality logs are being sawn into cants and lumber for export.

Sitka Spruce

Sitka spruce (fig. 8) is the second most important tree species in the hemlock-spruce type. Its range extends from northern California to Kodiak Island and the base of the Alaska Peninsula. Unlike most

Figure 8.--A large Sitka spruce in an old-growth stand being logged on Kosciusko Island, Alaska.

other major tree species within the type, its range is limited to a relatively narrow strip along the ocean, characterized by mild winters, cool summers, and abundant moisture. Sitka spruce requires abundant moisture throughout the year and will not tolerate prolonged summer drought.

In the southern part of its range as far north as northern Vancouver Island, Sitka spruce is restricted to low elevations along seaward-facing slopes; its range extends inland a few miles on alluvial bottom land along streams and on moist, north-facing slopes. In Oregon and Washington, merchantable trees are usually at elevations below 500 ft (150 m) but extending to 2,000 ft (600 m) where mountains lie close by the sea.

From central coastal British Columbia northwestward, Sitka spruce extends from sea level to timberline. In southeast Alaska, trees to 3,900-ft (1 200-m) elevation have been reported (Heusser 1954). Maximum elevation of merchantable trees is about 1,500 ft (450 m) on Prince of Wales Island, Alaska, and gradually lowers to 800 ft (250 m) or below on the tip of the Kenai Peninsula.

Total growing stock volume of Sitka spruce within the hemlock-spruce type has been estimated at 18.4 billion ft^3 (0.52 billion m^3)--63 percent in Alaska, 26 percent in British Columbia, and 11 percent in Oregon and Washington. In southeast Alaska, Sitka spruce is the second most abundant timber species, comprising 28 percent of the growing stock volume on commercial forest land (Hutchison 1967).

In Alaska and British Columbia, most of the better grades of Sitka spruce logs are sawn into cants or slabbed for export. Lower grade logs are used for pulp.

Western Redcedar

Western redcedar (fig. 9) is an important component of the hemlock-spruce type. Its range along the coast extends from northern California northward to southeast Alaska. Its northern range is rather sharply defined along the northern and western shores of Sumner Strait on Kupreanof and Kuiu Islands and extends to the vicinity of Petersburg on Mitkof Island (Andersen 1953). Temperatures during the growing season mainly determine the limits of its range (Gregory 1957b); but planted trees are capable of growing at least as far north as Juneau, 120 mi (190 km) north of the species known natural range (Harris and Farr 1974).

Within the hemlock-spruce type, western redcedar is found on poorly drained organic soils, often over hardpan, and on shallow soils over bedrock. Nearly pure stands may develop on the poorer sites, and more often mixed stands develop on the better sites. Best growth occurs on productive, well-drained sites, but on these sites cedar has difficulty competing with western hemlock and Sitka spruce and so is seldom found. In Alaska it is often found in stunted form on muskegs.

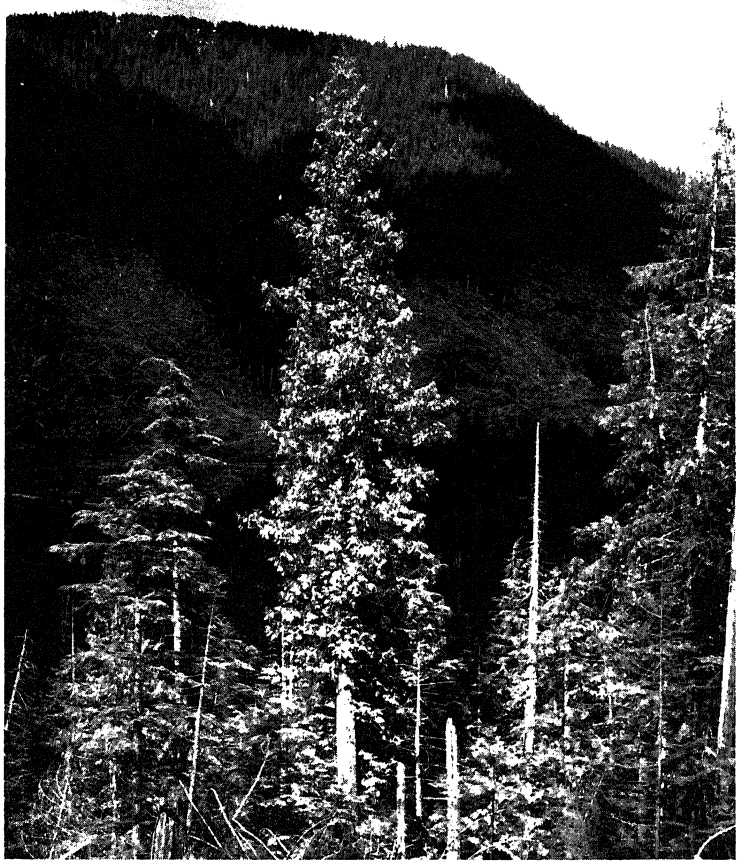

Figure 9.--An old-growth western redcedar. Maybeso Valley, Alaska.

In Oregon, Washington, and British Columbia old-growth western redcedar is in demand for lumber, shakes, and shingles. Younger trees from even-aged stands are used for poles.

In Alaska, quality is generally lower than farther south. Until a few years ago, there was little demand for the species in Alaska. Stands with a high percentage of cedar were not logged, and cedars encountered on clearcut areas were felled but often left in the woods. Now, however, good quality western redcedar logs are second only to Alaska-cedar in value. Most production is exported to Japan as round logs or rough cants. There is increasing interest in cedar pole production. No attempt is now being made to manage stands specifically for growth of western redcedar.

Douglas-fir

Douglas-fir is a common associate in the southern portion of the western hemlock-Sitka spruce type, becoming especially important on drier sites inland from the beach (fig. 10).

Douglas-fir ranges along the Pacific coast from northern California to northern Vancouver Island and on the British Columbia mainland north to the vicinity of Kemano. Two varieties are recognized, but only the typical coastal green variety (*menziesii*) occurs within the hemlock-spruce type.

Because of its value, resistance to damage by the white pine weevi and the availability of planting stock, Douglas-fir often has been planted in hemlock-spruce areas in Oregon, Washington, and southern British Columbia. The result has been a slow conversion from hemlock-spruce to Douglas-fir.

Alaska-cedar

Alaska-cedar occur in the hemlock-spruce type from Knight Inlet (about 51°N latitude), British Columbia (Perry 1954), northward and westward to Prince William Sound. It may be found from sea level to timberline (fig. 11).

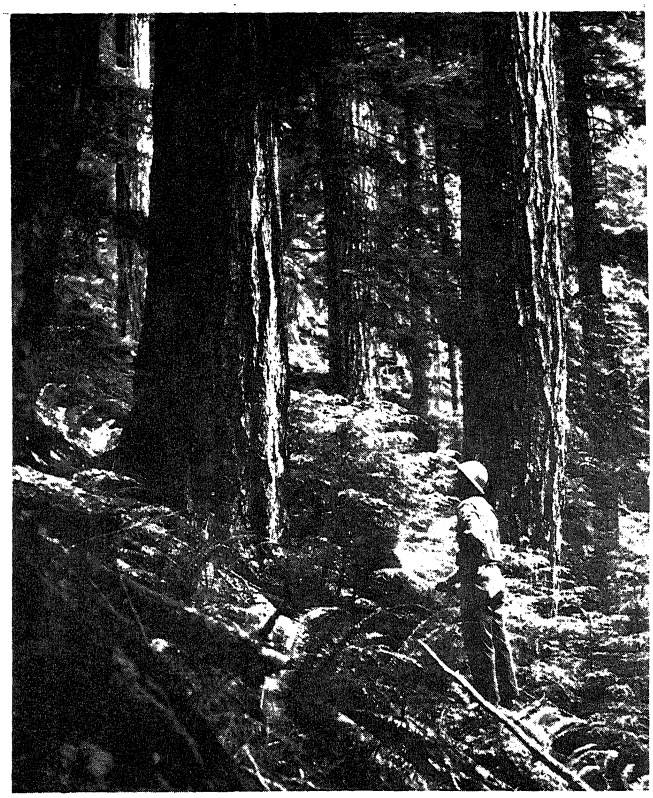

Figure 10.--Old-growth Douglas-fir, Whatcom County, Washington.

Figure 11.--An old-growth Alaska-cedar. Cape Fanshaw, Alaska.

In coastal Alaska, distribution of Alaska-cedar is scattered, both on the mainland and on many of the islands. The species can be found in nearly pure stands but occurs more often in scattered groups or individually in mixture with western and mountain hemlocks, Sitka spruce, shore pine, and western redcedar (Harris 1970). It is found as far north as Wells Bay in Prince William Sound (Viereck and Little 1972).

Best development is on thin organic soils over bedrock or occasion on deep, well-drained soils. On the better sites it has difficulty

competing successfully with western hemlock and Sitka spruce and is seldom found. It is a common component of scrub stands on organic soils and often occurs in stunted or shrublike form on muskegs.

The wood is aromatic and highly resistant to decay. Until recently, there was little demand for Alaska-cedar from southeast Alaska, and trees felled during clearcutting operations were left in the woods. Now, however, logs command top prices and high-quality trees are sought for harvest. The wood is prized in Japan, where much of the production is sent (Harris 1971a).

Little is known about the silviculture or management of Alaska-cedar; until recently no attempt was made to manage the species. Now, however, more interest is developing in planting of Alaska-cedar on high elevation sites where regeneration of other conifers has proved difficult, especially in British Columbia where experiments with container-grown seedlings are now being conducted (British Columbia Lumberman 1974). Although not a major commercial species, the wood is very valuable; more attention should be given to assuring its proper management in coastal Alaska.

Mountain Hemlock

Mountain hemlock (fig. 12) occurs in the hemlock-spruce type from northern British Columbia to Cook Inlet, Alaska, although its range

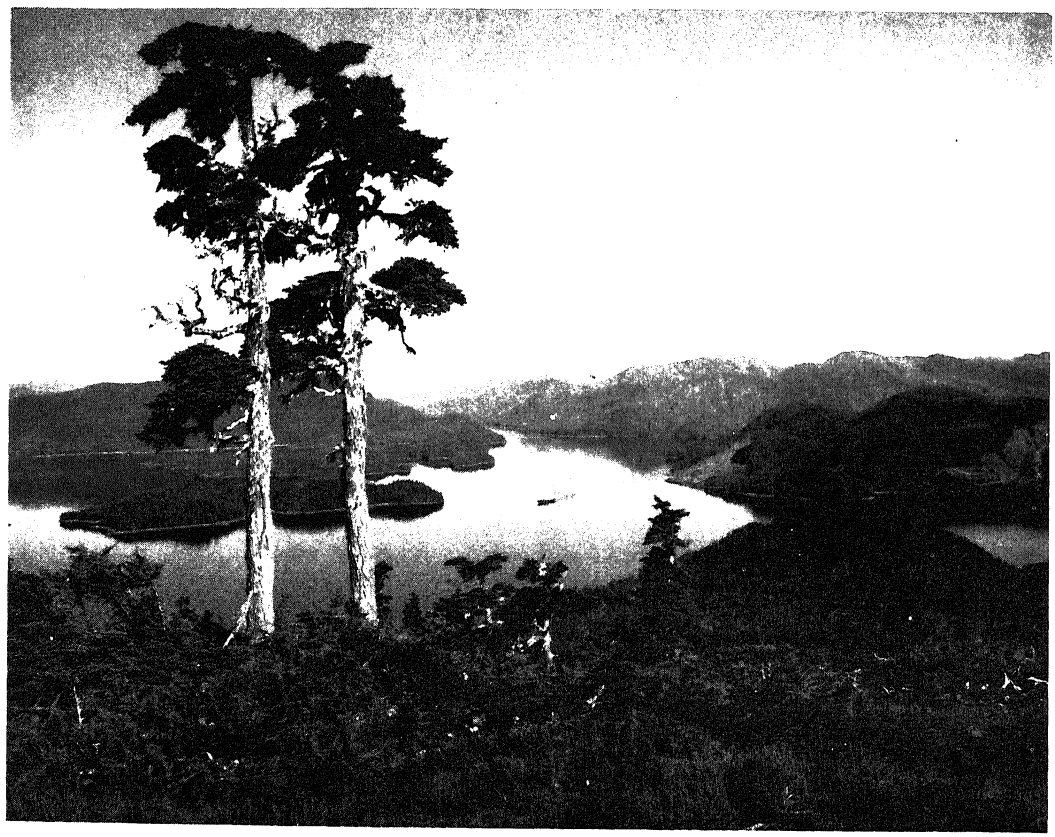

Figure 12.--Mountain hemlock near timberline. Harbor Mountain near Sitka, Alaska.

outside the hemlock-spruce type extends south to California and east to western Montana.

Mountain hemlock extends farther west and north than western hemlock, gradually replacing western hemlock as a major species on the Kenai Peninsula, Alaska. There it is able to survive more continental climatic conditions (less humid and greater temperature extremes) than other coastal conifers (Heusser 1960).

At lower elevations in southeast Alaska, mountain hemlock commonly is found on the poorer sites on organic soils. It is a major component along with western hemlock, cedars, shore pine, and Sitka spruce on noncommerical forest land fringing muskegs and often is found on muskegs in stunted or prostrate form. Near timberline, mountain hemlock is a major component of forest stands along with Sitka spruce, and it is often found in prostrate form on alpine meadows above timberline

Growth tends to be slower than that of western hemlock, even on the better sites, and it does not grow so large. Occasionally it occurs on good sites along with western hemlock and Sitka spruce. Best development is on well-drained soils.

Little attempt is made to manage mountain hemlock. As logging proceeds onto poorer sites and higher elevations, mountain hemlock will become a more important timber resource.

Alders

Three species of alder occur within the hemlock-spruce type. Red alder is found from California northward to the vicinity of Yakutat, Alaska. Sitka alder is found from northern British Columbia northwestward throughout the spruce-hemlock type in northern British Columbia and Alaska. Thinleaf alder has a restricted range along the coast in southeast Alaska (Viereck and Little 1972).

Sitka and thinleaf alders tend to have shrublike forms with multiple stems and rarely exceed 30 ft (9 m) in height. In contrast, red alder usually has a single, well-defined stem and may reach heights of over 100 ft (30 m).

In Alaska, alder is commonly found along beaches and streams, on avalanche tracks and landslides, and as a pioneer with Sitka spruce, willows, and cottonwood on land recently exposed by glacial outwash, retreat, or land uplift. Alders are also common on roadsides, landings, and wherever mineral soil has been disturbed (fig. 13). Alders are intolerant of shade, and in successional stands alder is usually shaded out after 40 to 60 years as it is overtopped by Sitka spruce. Red and thinleaf alders are seldom found above 1,000-ft (300-m) elevation, but Sitka alder may grow above 3,000 ft (900 m) (Harris and Farr 1974).

Organisms in root nodules on alders are able to fix atmospheric nitrogen and so improve soil fertility (Bond 1970, Tarrant 1964a, Tarrant and Trappe 1971). Additional benefits result from effects on soil chemistry, microbiology, and nutrient cycling (Lu et al. 1968, Zavitkovski and Newton 1971). Because of this, alder is able to grow on infertile soils and stimulate the growth of adjacent plants (Lawrence and Hulbert 1950).

Figure 13.--A young stand of red alder established following logging of a spruce-hemlock stand on an alluvial valley bottom site. Admiralty Island, Alaska.

Only red alder is of commercial importance. The wood is excellent for pulp and furniture (Plank 1971). It is the most important hardwood species in the Pacific Northwest; some 250 million board feet were logged in 1970 (Lawton 1972). It is also becoming an important pulp species. Recent changes in economics and technology have made possible whole-tree chipping of alder in the woods, including stems, branches, bark, and leaves. Bark is reported to be easily assimilated in the pulping process compared with thicker softwood bark (Western Timber Industry 1975). Red alder is an efficient converter of solar energy, and biomass from alder could supply energy for human use in the future (Smith 1978b).

In Alaska red alder is used for smoking fish and for carving but otherwise is not yet used commercially.

Red alder is only occasionally being managed as a timber resource and is still considered a weed by some forest managers. Efforts are being made to control the species where it competes with Sitka spruce and other conifers. Interest in red alder has, however, increased greatly in recent years (Trappe et al. 1968, Briggs et al. 1978). Red alder will likely increase in value as a commercial species.

Bigleaf Maple

Bigleaf maple occurs in the hemlock-spruce forests from California to northern British Columbia (fig. 14). Repeated searches have failed to locate specimens in Alaska, despite early reports of its occurrence (Viereck and Little 1972). Lack of moisture apparently limits its range to the south, and low temperatures are limiting northward. East of the hemlock-spruce type, the species occurs inland to the Sierra Nevada and Cascade Range.

Optimum growing conditions are found in the humid climate of western Oregon. Best development is on deep alluvial soils near streams, although it also occurs on a variety of soils from deep loams to thin soils on rocky slopes.

Seeds of bigleaf maple are eaten by small mammals and birds; in the sapling stage, bigleaf maple provides browse for black-tailed and mule deer and for elk.

Maple syrup has been made from the sap of bigleaf maple. Past experience has shown that annual sap flow averages from 3 to 6 gal (11 to 23 liters) per tree; about 35 gal of sap are required to make 1 gal of syrup. Although there are no records of commercial production, syrup production as a hobby or small enterprise would seem feasible (Ruth et al. 1972).

Figure 14.--A stand of bigleaf maple on bottom land along the Santiam River, near Jefferson, Oregon.

Black Cottonwood

Within the hemlock-spruce type, black cottonwood is found primarily in the major river valleys and on outwash plains, usually in association with Sitka spruce, willows, and alders. In Oregon and Washington, it is common bordering tidal flats and channels all along the coast (Franklin and Dyrness 1973).

Black cottonwood is found primarily in the major river valleys and outwash plains on the southeast Alaska mainland (fig. 15). Major occurrences are in the Unuk, Chickamin, Stikine, and Taku

River Valleys, in many valleys in the vicinity of Lynn Canal, and on glacial outwash plains near Yakutat. A few stands occur in island valleys in the vicinity of Sitka. Occasional trees can be found in scattered locations on the islands near present or former habitations where they may have been planted. Black cottonwood has been used for pulp and furniture in Oregon. In Alaska, it has been logged along with Sitka spruce and western hemlock in clearcutting of primary stands. The market has not, however, been stable and the species is not consistently sought for harvest. The wood has been tested in Alaska for use as dissolving pulp, but at present there is no market. The tree is often planted as an ornamental because of its fast growth and handsome form; however, the wood is brittle, and exposed trees are subject to wind damage.

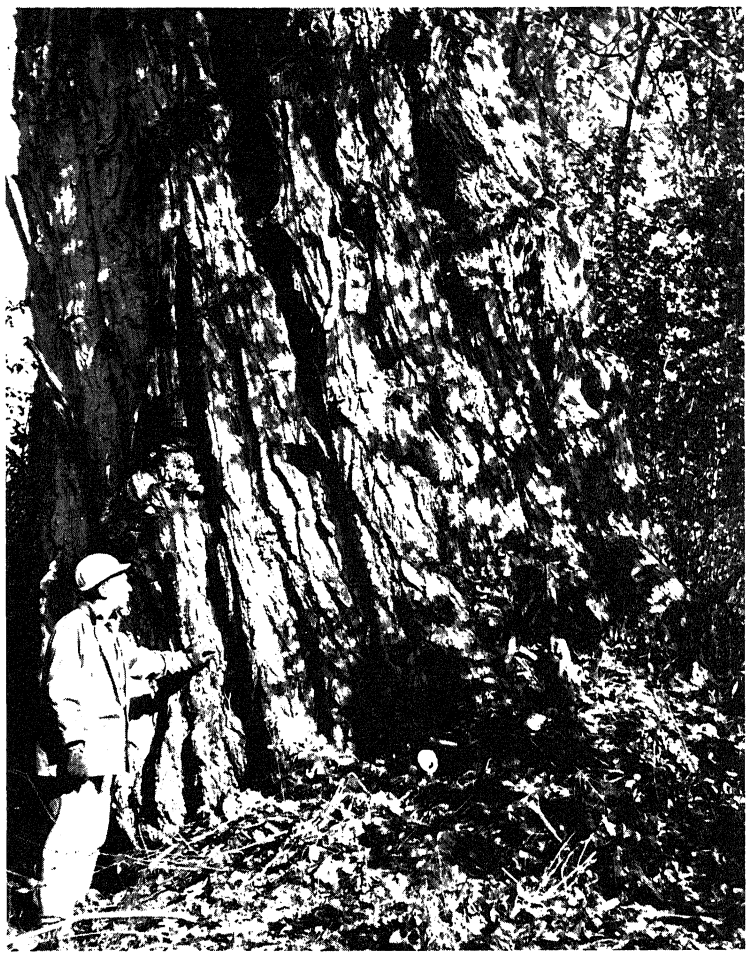

Figure 15.--Few black cottonwood are as large as this 10-foot (3-m) diameter specimen located near Klukwan, Alaska.

INITIATING TIMBER MANAGEMENT

In the northern portion of the hemlock-spruce type, most of the forests have never been logged. Almost everywhere else, someone has gone before--some plans are made, some roads are in, some timber cut--and the manager must go from there. In Alaska and parts of British Columbia, the manager can start from scratch, fortunate enough to have information and experience from farther south and from other forest types as guides.

In southeast Alaska, old-growth stands occupy about 87 percent of the productive forest land area (Hutchison and LaBau 1975). The current approach on National Forest land in coastal Alaska is to develop management plans, based on recommendations from multi-disciplinary teams, that integrate all aspects of forest protection and use. The result places many restraints on road construction and harvest cutting.

Our discussion is organized to stress silvicultural practices. Restrictions needed to protect basic soil and water resources are described where they tie into the silvicultural practice under discussion. Special sections on forest protection and multiple use are presented later.

LOGGING PLANS

Moving into an undeveloped drainage to make harvest cuttings needs careful advance planning. The initial road system serving areas to be cut may go through intervening areas of green timber reserved for later harvesting. This road system should be designed to serve not only the cuttings of the first entry but also the reserve areas. Otherwise, the reserve areas may not be logical logging units and the roads may not serve them efficiently.

A common procedure is to make a tentative layout of all roads, landings, and cutting boundaries on aerial photos or topographic maps of the area. These are taken into the field where obstacles to application of the plan can be spotted during reconnaissance. The plan is altered to fit conditions on the ground, and a final pattern of roads and landings to serve the entire area is developed. This becomes the forestry-logging plan for the area (Ruth and Silen 1950).

The areas to be harvested during the first entry should be identified as one of the last steps in the planning process--after the planning team is thoroughly familiar with the area. The most decadent stands should be harvested first and converted to vigorous young stands. They are best identified when the forestry-logging plan is being checked in the field. Only the roads to serve these particular areas are designated for initial construction.

Sophisticated planning is needed when skyline yarding systems are used. Burke (1975a, 1975b) described one planning technique particularly adapted to skylines; desk top calculator, plotter, and digitizer facilities are used to analyze alternate skyline lead paths. Projected skyline roads are then plotted on a topographic map and coordinated with a proposed road system which can be evaluated with the same equipment. Tentative plans can be plotted by the equipment and viewed in perspective--as one would look at roads, landings, and cutting boundaries plotted on a relief map.

Whatever the planning system used, it is critical that roads and landings be coordinated for maximum overall efficiency and that the road system serve the reserve areas to be harvested later.

Many factors besides the coordination of road spacing and yarding must be considered in preparing a forestry-logging plan. Foremost is protection of the basic soil resource. Roads and landings must not cause erosion. Generally, this means locating them away from streams. Stream crossings should be limited, made where disturbance will be minimum, and carefully planned to avoid stream siltation.

The selection, layout, and operation of the yarding system must be controlled to provide an appropriate level of disturbance to the site, enough to facilitate regeneration of the stand but not enough to cause loss of soil. In many cases the high-lead system with logs dragged on the ground may be used. Care must be taken with downhill yarding because high-lead skid trails tend to concentrate runoff and may lead to soil erosion. Less disturbance will result from grapple yarding which normally lifts one end of the log free of the ground. In other cases, both ends of the log should be lifted free. At the other extreme the disturbance caused by rubber-tired skidders or crawler tractors may concentrate runoff and lead to erosion. Where soils are poorly developed, heavy disturbance often leads to serious damage to the soil and invasion by competing vegetation.

Another important factor is public use, particularly recreational use on public land. This affects such items as road standards, size and arrangement of harvest cuts, scenic strips along main waterways, and buffer strips along streams. Arrangement of cuttings to minimize wind damage and facilitate fire protection is an important factor to be discussed in detail later.

Adjustments in the forestry-logging plan to meet wildlife management objectives may be important, such as leaving areas uncut to protect eagle nesting trees or deer winter range.

Preparation of the forestry-logging plan and initial development of a road system for a hemlock-spruce drainage mainly determines the future character of that area. If roads are located for timber access alone, they may not be in the best location for recreational use. The converse also is true. Land use objectives should be carefully determined in advance. Timber harvesting determines the distribution of age classes available for the next rotation, so effect of the initial plan extends indefinitely into the future. The many undeveloped hemlock-spruce areas in Alaska provide an excellent opportunity to prepare comprehensive forestry-logging plans that consider all land use objectives.

ROADS

Location, construction, and maintenance of roads are important activities of the land manager. Roads are needed for access but are costly to build and maintain and can be a source of erosion, sedimentation, and other adverse effects on the environment. Roads needed for timber harvest usually range from 5 to 7.5 mi/mi^2 (3.1 to 4.7 km/km^2) of land area; but more or less may be needed, depending on average yarding distance. Skylines reach out longer distances and require

less road than conventional high lead or grapple yarding systems (Burke 1975a, 1975b). In special situations helicopters may be used so that fewer roads are needed. Greater road mileage is required where clearcuts are small or where the shelterwood or selection system is used and logs must be yarded through standing timber. For example, small clearcuts of 10 acres (4 ha) or less or use of the selection system may require construction of 7.5 mi of road per square mile (4.7 km/km^2) cut, although clearcuts of 100 acres (40 ha) might require only 6.3 mi/mi^2 (3.9 km/km^2) (Staebler 1971).

Roads also take land out of tree production. Silen (1953) examined roads on a steep Cascade Range watershed and found 9.8 percent of the area disturbed by construction of roads and landings. This area was not all lost to timber production because some of the disturbed area will reforest and roots and crowns will encroach under and over road and landing areas. Production loss was estimated to be 4.1 percent.

The wider the interval between roads the longer the yarding distance and the higher the yarding cost. The most economic road spacing for harvesting a timber crop is when the combined costs of road construction and yarding are a minimum. If only a single harvest of the timber is considered, a cost analysis would indicate minimum road construction and relatively long yarding distances. If yarding costs for thinnings and harvest cuttings during future rotations plus costs for administration, fire protection, and other values of roads are included in the analysis, results will indicate closer spacing of roads and shorter yarding distances. Roads have some disadvantages too. Besides construction and maintenance costs, there are added risks of erosion and mass soil movement, land taken out of production, and adverse effects on the environment. These too must be included in the analysis. Road location should be based on capabilities of the yarding equipment to be used. Yarding techniques have changed over the years, however; and planning a permanent road system runs the risk that a different yarding technique will be used in the future and the road will not be suitably located for it. A common practice in Oregon and Washington has been to locate roads on the outer edge of benches where cables can be used to reach down the steep slope and yard logs up from below and tractors can be used to yard logs down the moderate slope of the bench to the road. With increasing emphasis on minimizing soil disturbance, tractors and rubber-tired skidders often are avoided in favor of cable yarding which usually works best for yarding logs uphill. In Alaska, roads are usually built near valley bottoms and logs are yarded both uphill and downhill. Grapple and skyline yarding, which are gaining rapidly in popularity, require a concave yarding profile to provide lift for the logs. Careful road location can do much to increase the proportion of yarding areas with suitable configuration, but the result will be a different road system than one planned entirely for high-lead yarding.

Intensive management requires good access, so trends in road location are toward closer spacing. Most areas now being logged have never been thinned and a primary objective of road location is removal of the natural stand by clearcutting. There are no residual trees in the way and yarding distances can be long. The next rotation, however, will be managed more intensively. Thinnings usually will be needed, and logs will have to be yarded through a residual stand. This will

re shorter yarding distances. In general, where more intensive ement is anticipated, it is best to opt for closer road spacing that needed for large-scale clearcutting.

Whatever the road spacing selected, it is important to minimize length. A systematic road pattern will provide access with less mileage than a random pattern (Burke 1975b). Silen (1955) ed efficient road patterns in a watershed similar to many in the ck-spruce type and recommended that a high proportion of a age be served by parallel road levels spaced at the economic val. There should be a minimum number of roads that climb en levels. When two roads fork, it is desirable that the fork an area where the roads can separate quickly and each serve its complement of timber. It is inefficient to have two parallel closer than the road interval that is most economical.

Road construction usually has a greater effect on stability and on of soil than any other forest activity. Building a road s a steep side slope changes drainage patterns, undercuts the l slope, and if waste material is sidecast, adds overburden to ower slope. Mass soil movement may result. Full bench construc- is best on unstable slopes with waste material hauled away and ited on stable areas. Roads should be adequately crowned and ed and surface runoff distributed through culverts to the forest below the road. In Alaska almost all roads need to be rock ced because of the wet climate and fragile soils (fig. 16).

Figure 16.--A typical rock-overlay logging road under construction on Prince of Wales Island, Alaska.

Even so, log hauling causes some muddying of the road surface. The mud gets into ditch water and eventually to the downhill slopes. In Oregon and Washington some main access roads have been paved to reduce maintenance costs and minimize runoff of muddy water. It is best to locate roads and surface-water culverts so the water flows through a filtering area of forest floor material before entering a stream (Sommer 1973, Swanston and Dyrness 1973). Culverts placed in streams with fish populations must allow fish passage. Open-bottom structures may be preferred over pipes because there is less chance of creating an impassable waterfall at the lower end of the culvert (USDA Forest Service, Alaska Region 1977) (fig. 17).

Figure 17.--These culverts were improperly installed above the streambed and will not allow upstream passage of resident coho and trout. Kuiu Island, Alaska, 1975. (Photo, courtesy of Alaska Department of Fish and Game.)

An objective of location and design of roads should be to minimize construction and maintenance costs, exposure of mineral soil and resulting erosion problems, the visual impact, and land taken out of production. This may be accomplished by avoiding steep slopes, reducing depths of cut and fill, and generally minimizing the volume of excavated materials. Road standards should not be higher than needed for timber hauling and other planned uses.

HARVESTING EQUIPMENT

Early day yarding of hemlock and spruce was mostly done by large steam skidders; logs were transported by railroad in Oregon and Washington and by rafts in British Columbia and Alaska. Use of trucks

or hauling logs began before World War II. Now almost all logs are oved to the mills by truck in Oregon and Washington and by truck to ransfer points for further barging or rafting to the mills in ritish Columbia and Alaska.

A trend toward tractor yarding on moderate slopes, readily pparent in the Douglas-fir type, has not developed in the hemlock-pruce type because of soil conditions. Yarding with crawler tractor nd rubber-tired skidders now is avoided on many areas because of wet oil and associated problems of soil compaction and because skid oads change the drainage pattern and may cause soil erosion. Cur-ently, cable yarding is the rule and ground equipment the exception. high-lead system with portable spar; main, haulback, and straw ines; butt rigging; and chokers is still in general use, especially n Alaska (fig. 18).

Grapple yarding, in which logs are grasped with a mechanical rapple and yarded perpendicularly to the road with a running skyline ystem, is currently gaining wide acceptance, especially in Oregon nd Washington (Sommer 1973). Yarding distances usually do not xceed 800 feet (240 m), similar to most high-lead yarding.

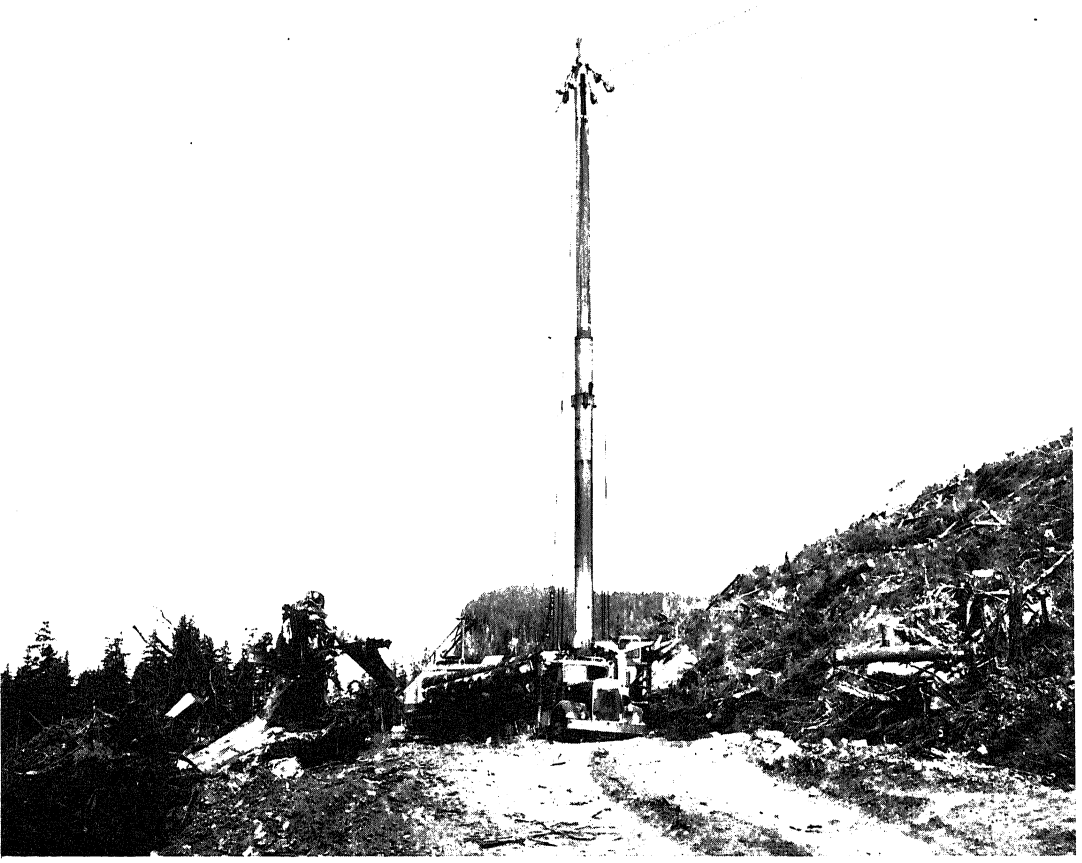

Figure 18.--A high-lead logging operation using a portable steel spar, Tongass National Forest, Alaska.

With grapple yarding most logs come in with the front end lifted clear of the ground. There is much less disturbance of forest residues and ground vegetation and exposure of mineral soil than with high-lead yarding. This reduces erosion potential and damage to advance regeneration but may not expose enough mineral soil for seedling establishment.

Grapple yarding may be done at night, with floodlighting of the yarding area and the landing. Many operators in Oregon and Washington run two shifts to speed production during summer months and to better utilize equipment. One loading shift usually can load logs from two yarding shifts (Burke 1972).

Skyline yarding systems are used in special situations, such as areas of very steep slopes or erodable soil where road construction and site disturbance must be held at a minimum. Skylines can reach out the long yarding distances required. They can lift one or both ends of a log free of the ground during yarding, an increasingly common contract requirement. Logs may be suspended for yarding across streams and streamside leave strips. Skylines may be used for overstory removal with minimum damage to the understory. Those with lateral yarding capability may be used for shelterwood harvesting or thinning (Carson and Jorgensen 1974, Mann 1977).

Helicopter and balloon yarding have been used experimentally in the hemlock-spruce type. They offer alternatives for very long yarding distances or where roads should not be built.

SILVICULTURAL SYSTEMS

Almost all hemlock-spruce harvest cuttings have been by the clearcutting system although any of the four basic silvicultural systems--clearcut, seed tree, shelterwood, selection--or various combinations may be used.[4/] Except for problems of competing vegetation to be discussed later, regeneration can be attained with any silvicultural system or combination of systems. The manager's main focus, therefore, is on economics, future growth and yield, and integration of timber harvest with other forest values.

A basic objective always is to protect soil, water, and related resources. It would be shortsighted to harvest a particular timber crop in any way that would jeopardize production of future crops on the area. If protecting these resources makes logging costs prohibitive, harvesting should be delayed until economic conditions change or new technology is developed.

Probably it would be difficult to design a system that would do more than delay establishment of tree seedlings. The usual problem is too much regeneration, leading to costly precommercial thinning or, without this, to overstocked stands (fig. 19). Where possible, harvest cutting techniques should be modified to limit regeneration, but it may be best to aim for extra seedlings as insurance and to encourage selection of seedlings through early thinning or natural competition. An alternative is to strive for the desired number and, if openings occur, fill in by planting. In any event it seems best

[4/] For definitions of silvicultural terminology, see Ford-Robertson (1971).

Figure 19.--Natural regeneration of western hemlock-Sitka spruce is often too dense; 10 years after clearcutting, this stand contained approximately 15,000 trees per acre (37,000/ha).

strive for a postlogging environment that will limit the number of edlings rather than one that will be ideal for seedling establishment.

Inefficient use of growing space in hemlock-spruce areas can cur in several ways. Foremost is the preponderance of climax ands in northern parts of the range; net growth of a climax stand zero and near-climax stands not much more. Numerous areas are minated by unwanted vegetation. Other areas have too many or too w trees; having too many distributes growth to many small stems and ving too few leaves openings in the stand. Openings will eventually generate, but the delay causes a loss of production.

Silvicultural systems may be selected to maximize timber production, t many other objectives are possible. Managing stands in recreation eas, maintaining or improving the scenic beauty of the forest, otecting watersheds and streams and providing or maintaining forest ands for wildlife are important considerations in many areas.

Whatever the objectives of a proposed silvicultural system, is important that they be fully understood. The silvicultural stem adapted must be in harmony with the goals of the landowner. r example, the owner of a small acreage may wish to maintain recrea- onal values and so might favor the selection system. The industrial ner who has timber production as a main goal would usually favor earcutting and even-aged management. Most public ownerships have ltiple objectives, and various zoning systems are used to identify minant-use categories. The basic silvicultural systems will be scussed here, primarily in terms of how they meet timber management

objectives. Invariably there will be multiple and usually conflicting objectives. Some of these are discussed in the section on multiple use. The forest manager must make proper trade-offs and write the silvicultural prescription that will provide the best overall results.

SHELTERWOOD SYSTEM

The basic characteristic of the shelterwood system is establishment of a new crop before completion of the preceding rotation; this provides an overhead seed source and overstory protection during seedling establishment. Hemlock and spruce lend themselves admirably to shelterwood cutting because both readily become established under a forest canopy (fig. 20). Shelterwood cuttings resemble heavy thinnings and use of this method logically follows a series of commercial thinnings in immature stands. The classical shelterwood prescription involves three kinds of cuttings: (1) *Preparatory cuttings* which stimulate seed production and decomposition of humus on the forest floor, (2) *seed cuttings* which let in more light and prepare the seed bed, (3) *removal cuttings* which release established seedlings (Smith 1962).

Figure 20.--Natural regeneration coming in under shelter of a Sitka spruce-western hemlock overstory. Cascade Head Experimental Forest, Oregon.

An exploratory study of shelterwood cutting on the Oregon coast serves as an example in hemlock-spruce (Ruth 1967a). A 104-year-old stand was thinned about 20 percent, leaving about 76,000 bd ft per acre (360 m^3/ha). The stand had not been scheduled for harvest cutting, and initially this cut was considered an improvement thinning to take out dead, dying, and defective trees; however, hemlock and some spruce seedlings promptly became established under the stand, so a decision was made to call the thinning a seed cut in the shelterwood system and follow through with removal cuttings.

The seedlings grew well the first few years, then slowed as the overstory canopy closed. Numerous spruce and some hemlock seedlings began to die. Nine years after the thinning, when the understory was 51 percent stocked, an additional 27,000 bd ft per acre (130 m^3/ha) was removed from the overstory, leaving a crown closure of about 60 percent. The logging operation reduced stocking to 35 percent, but during the next three growing seasons it increased to 60 percent. Then at this 12-year point, the area was split in half and each half treated separately. They had similar topography and aspect.

On the north half, three more seasons brought stocking up to 94 percent with seedlings up to 8 ft (2.4 m) tall. There were thousands of seedlings per acre. Complete removal of the overstory using crawler tractors reduced stocking to 55 percent. This was a reasonable amount had distribution been better; but there were too many seedlings in most areas, and a badly disturbed area around the landing had too few. In general the 1st year, released seedlings had poor vigor and a yellow appearance, apparently from abrupt exposure to the sun. At first, the area looked much like a normal clearcut, but the established seedlings recovered quickly and soon hid the stumps from view. The landing area was slowest to recover.

On the south half, three additional growing seasons brought stocking up to 73 percent and seedlings up to 8 ft (2.4 m) tall. A two-stage overstory removal was prescribed. The first stage was completed, during the 15th year after the first thinning, by removing 63 percent of the overstory. This reduced stocking to 67 percent. At last measurement, stocking again was increasing and understory trees were up to 20 ft (6 m) tall. The stand still is esthetically attractive. The next objective will be to remove the remainder of the overstory with minimum esthetic impact and with some control over stocking in the new stand.

This exploratory study showed that shelterwood cutting resulted in establishment of a new hemlock-spruce stand, but overstocking was a problem. The overstory was too dense to maintain spruce in the understory. Seedlings suffered shock from abrupt overstory removal. The study also showed that the shelterwood system offers great flexibility in that the overstory can be either removed promptly after seedling establishment or left for several years to take advantage of changing market conditions or to grow understory seedlings to a desired height.

Another study in an unthinned 60-year-old hemlock stand in western Washington also showed overstocking to be a problem (Williamson and Ruth 1976). This was a three-cut shelterwood with a seed cut and two removal cuts. There were 12 cutting intensities, leaving basal areas ranging from 235 ft^2 to 38 ft^2 per acre (54 to 9 m^2/ha).

Before the seed cut in 1960, the stand was stocked with an average of 2,220 advance regeneration seedlings per acre (5,480/ha). The first cut destroyed many of these, leaving an average of 650 seedlings per acre (1,600/ha). More subsequently died from logging damage and natural mortality so that only 280 per acre (690/ha) were left 2 years after the removal cut in 1971. During this time, postlogging regeneration was prolific and there were 18,500 seedlings per acre (45,700/ha) by the final measurement in 1971. Response varied by cutting intensity but in all cases gross overstocking occurred (fig. 21). Eleven years after the regeneration cut and immediately after the harvest cut, postlogging regeneration averaged 4.6 ft (140 cm) in height.

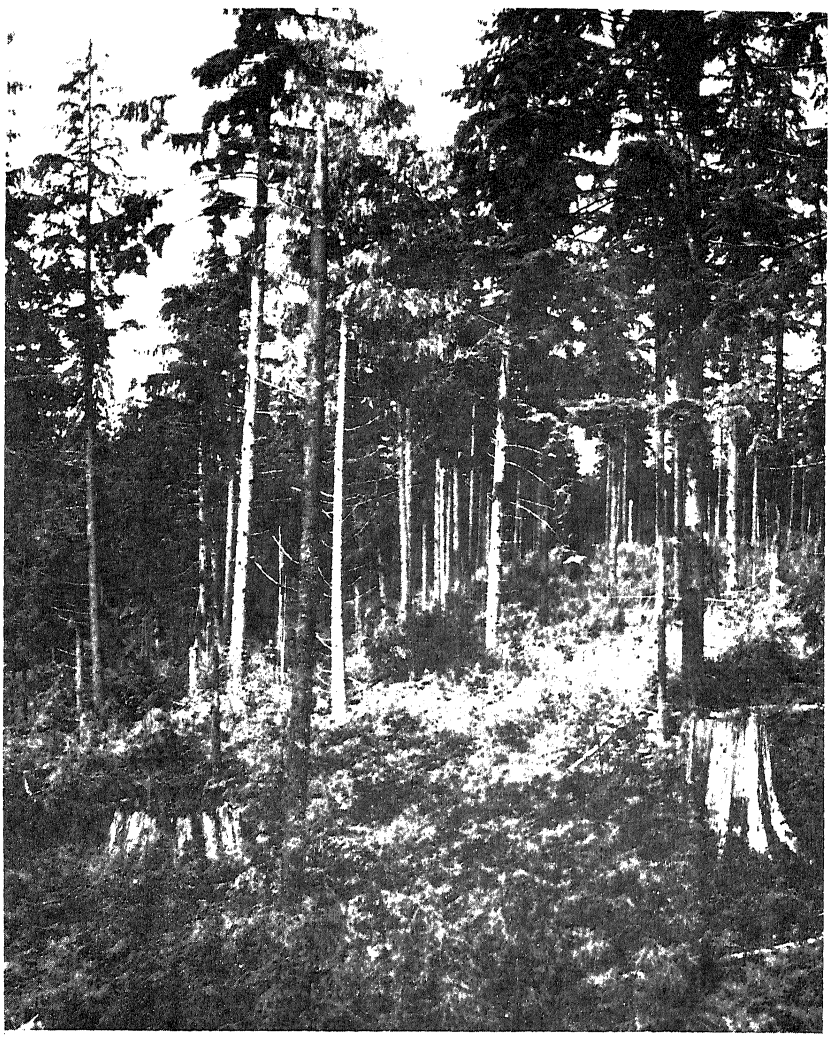

Figure 21.--Eight growing seasons after the first cut and just before the final cut, regeneration was dense. Average height of tallest seedlings on milacre plots was 4.0 ft (1.2 m), Hemlock Experimental Forest, Oregon.

The long conversion period in this study allowed time for seedlings to grow above stump height before removal of the final overstory; this helped to maintain a forested appearance. For seedling establishment alone, the period could have been shorter. For example, under the most open shelterwood, it may have been better to remove all the overstory 4 years after the seed cut rather than just half. There were 6,400 seedlings per acre (15,800/ha) at that time. Waiting 4 more years with an overstory seed source aggravated the overstocking.

With a short conversion period, dense overstories also held down numbers of seedlings. The two most dense overstories of 210 and 235 ft^2 per acre (48.2 and 54.0 m^2/ha) had an average of 3,200 seedlings per acre (7,900/ha) in the understory 4 years after the seed cut. Logging half the overstory, plus a year of growth, left the seedling count the same. In 4 more years it increased to 16,500 per acre (40,800/ha). Logging all the overstory at one time might have reduced the seedling count to a more desirable number. Dominant seedlings ranged from 6 to 15 ft (1.8 to 4.6 m) tall on the treatments with low overhead density. Heights were progressively shorter as density and shade increased.

These studies suggest that overstocking of regeneration can be expected with the shelterwood system. Providing an overhead seed source and protective shade improves the environment for seedling establishment, but growth rate of seedlings is slower under shade.

Damage to the residual stand can affect growth and mortality during the conversion period, and decisions should be made on how much effort to expend to minimize losses. With a short conversion period, there is little time for decay to become established and spread, so most volume loss will result from direct physical damage. A long conversion period runs the added risk that decay from stem or root damage will reduce growth and yield.

Many hemlock-spruce stands are stocked with advance regeneration prior to clearcutting, and enough seedlings survive the logging operation to form a new timber stand. These cuttings have been classed as clearcuttings but actually meet the definition for shelterwood cutting in that regeneration is established before removal of the overstory. They might be termed accidental or unplanned shelterwoods. If the seedlings become established under an unthinned stand and the stand conversion is accomplished with one cutting, this could be called a one-cut shelterwood--certainly the system in it simplest form. If a mature stand has been commercially thinned prior to the final cut, the last thinning might be thought of as a seed cut and the stand conversion as a two-cut shelterwood.

It appears that whether a harvesting system is clearcutting or shelterwood cutting is partly a matter of definition and whether or not the establishment and utilization of advance regeneration were part of a silvicultural system. Whatever the terminology, the presence of advance regeneration is increasing rapidly with the spread of commercial thinning in hemlock-spruce stands. Increasing use of the last commercial thinning as a seed cut to encourage regeneration is a logical development.

Residues in shelterwood areas generally are left unburned because danger of fire under the shade of a residual stand is low. It increases after overstory removal but soon decreases again as seedlings overtop residue material and shade it from the sun. If fire danger warrants, residues not in contact with the soil may be lopped and scattered to increase moisture content and speed decay. Extra fire protection may be provided if necessary.

Residues from inital cuts may be piled in the larger openings and burned. Hand piling usually is preferred over machine piling because heavy machines are limited to gentle slopes, may compact the soil, damage established regeneration, damage roots of the residual stand, and expose mineral soil to erosion.

Controlling Species Composition

The shelterwood system may be used to control sunlight reaching the forest floor and thus provide some control of species composition in the regenerating stand. Deep shade favors hemlock, moderate shade permits addition of spruce, light shade permits establishment of Douglas-fir and red alder (Ruth 1967a).

Under a forest canopy, the environment is cool and moist, and organic seed beds, in addition to mineral soil, are satisfactory for seedling establishment. Minore (1972) examined regeneration under hemlock-spruce stands near the Oregon coast. In the deep forest with less than 10-percent sunlight reaching the forest floor, seedlings were found on rotten logs but not on the duff-covered forest floor. Almost always they were pure hemlock. With 10- to 40-percent sunlight, both hemlock and spruce occurred on both logs and the forest floor, but both were taller on the logs. With 40- to 60-percent sunlight, both logs and the forest floor were excellent seed beds. In full sunlight both were unsatisfactory seed beds. But if well established in the shade, some hemlock seedlings survived logging operations and went on to form the nucleus of a new stand.

Hemlock regeneration can be favored by maintaining a dense to moderate overstory and organic rather than mineral soil seed beds. A moderately dense overstory and mineral soil seed bed encourage spruce along with the hemlock. A light overstory or no overstory and mineral soil will encourage the addition of Douglas-fir and red alder where a seed source is present. A common objective is to prevent encroachment of red alder on conifer sites, so maintaining a moderately dense overstory and minimizing mineral soil seed beds will help. Opening the stand too much can increase risk of blowdown. Exact overstory densities cannot be specified, but local observation of alder encroachment should be helpful in making this decision. Alder will become established on mineral soil seed beds under denser shade than on organic seed beds.

Control of species composition also may be accomplished by controlling the seed source. For example, the objective may be to favor hemlock over Sitka spruce regeneration in an area where spruce saplings would be damaged by the white pine weevil. Under the shelterwood system, spruce can be thinned from the overstory during the seed cut, thereby reducing the seed supply.

Whether to use the shelterwood system in hemlock-spruce depends on several factors. Economic comparisons with clearcutting are not available, but logging costs are higher with shelterwood cuttings because several entries are made into the stand and precautions must be taken to protect first the residual stand and later the established seedlings. On the other hand, the shelterwood system has an economic advantage in that the new stand gets started while growth continues on part of the old stand, so there is some overlapping of rotation. In part it avoids the period right after clearcutting when seedlings are too small to fully occupy the site.

Commercial thinning in hemlock-spruce stands in Oregon and Washington encourages establishment of natural regeneration in the understory, so by the end of a rotation a new stand may already be established. Unless there is some reason to destroy this new stand,

the main concern of the land manager will be how tall to let the seedlings grow before removal of the overstory, and how to control the logging operation to leave a desired number and distribution of seedlings. Cost increases may be more than offset by the advantage of early seedling establishment. More research on and experience with shelterwood cutting are needed, but the system appears destined for wider use in hemlock-spruce.

There are special situations where the shelterwood system should be used in preference to clearcutting, even though a seed cut may not be needed to encourage establishment of regeneration in the understory. These include areas where it is essential to maintain a continuous ground cover, either for esthetic purposes or to prevent erosion. The shelterwood system can minimize encroachment of intolerant vegetation, such as red alder and bracken fern. Compared with clearcutting, shelterwood cutting can be used to favor hemlock over spruce regeneration, a particularly appropriate objective where the spruce weevil is a problem.

There are also situations where the shelterwood system should not be used. These include areas infected with dwarf mistletoe. Regeneration will be infected by seed showering down from the overstory; this perpetuates the disease. This system should also be avoided in overmature old-growth stands where trees are large. Yarding the large logs can damage the residual stand; residue accumulations are difficult to treat; residual old-growth trees may suffer from exposure or wind damage; and regeneration is easily damaged during overstory removal.

SELECTION SYSTEM

The selection system is aimed at creation or maintenance of uneven-aged stands. It involves removal of trees singly or in small groups at short intervals, continued indefinitely. Small even-aged groups of seedlings appear in the openings thus created. Regulation of the forest is based on development and maintenance of a range of tree diameters, with many trees in the smaller diameter classes and progressively fewer in the larger diameter classes.

A main advantage of the system is that a high forest cover is maintained on the area. Esthetic appeal is maintained, and there is greater stability of environmental conditions for associated animals and plants. The selection system may be used to discriminate against intolerant species by restricting the size of openings in the forest. Thus, it might be used to limit regeneration of red alder, Douglas-fir, and Sitka spruce.

A disadvantage of the selection system is that frequent entries must be made into the stand to remove individual mature trees or small groups of trees. Frequent entries increase the chance of logging damage to the residual stand. Damage to crowns and stems would be a problem on steep slopes that must be cable-logged. With ground equipment, soil disturbance, compaction, and root damage become problems.

Residual, old-growth trees often die from exposure or wind damage (Isaac 1956). Logging costs would be high because relatively small amounts of timber would be removed at a time. Logging would be more complex than with other systems and would require more skill and supervision to prevent damage.

Converting older, even-aged stands with trees of fairly uniform, large diameters to uneven-aged stands with a progression of diameter classes would be a lengthy process. Conversion of near-climax stands having several age classes would also be difficult because of large log sizes and generally defective timber. The selection system would not be suitable for hemlock stands with dwarf mistletoe infection.

Despite these problems, the selection system merits consideration. Selection cutting may have application in scenic areas where both an esthetically appealing forest cover and commercial timber production are desired. It may also be a valuable tool for maintenance of deer habitat in the northern portion of the type. It may not be suitable for recreation areas where open understory conditions are preferred. The system has not been formally tested in the hemlock-spruce type; it should be.

SEED-TREE SYSTEM

In the seed-tree system, selected trees are left standing to provide seed for regeneration. This differs from the shelterwood system in that so few trees are left that they do not provide appreciable overstory protection for the regenerating stand. Hemlock-spruce may be regenerated by seed trees, but the method is rarely used for several reasons. Overdense regeneration usually occurs without the extra seed provided by seed trees; exposed seed trees often uproot or break off in winter storms; and it is costly to harvest the seed trees at a later date.

From the standpoint of timber production, the seed-tree system has little to recommend it. Leaving seed trees of a particular species could theoretically increase the proportion of that species in the new stand or lead to genetic improvement by selecting superior trees. Both of these objectives, however, would be better achieved by planting. The cost of later harvesting isolated seed trees, or losing them to wind, could go toward financing more intensive cultural measures.

From the standpoint of wildlife management, the seed-tree system might be integrated with a program of snag management. In situations where snags are desired for nesting or perching sites, selection of seed trees could be based on their suitability for wildlife habitat as well as for seed protection.

CLEARCUTTING SYSTEM

Clearcutting is by far the most common method of timber harvesting in hemlock-spruce stands. It is less costly than other methods because taking all the trees at one time permits spreading fixed costs over large volumes per acre. It concentrates the logging, roadbuilding, and administrative problems into a smaller portion of the forest (fig. 22). It avoids the need to protect residual trees that must be left on the logging area with other silvicultural systems. Clearcutting reduces the number of entries into a stand, an especially important saving in Alaska where it is expensive to set up and maintain logging camps. It is the only system that makes large-scale harvest cuttings economically feasible in Alaska today (Harris and Farr 1974). From the cost standpoint, it is the obvious choice for hemlock-spruce stands.

Figure 22.--Clearcuts near Sitkoh Lake, Chichagof Island, Alaska.

In general, clearcuts become overstocked and stocking control is irable. The main exception to this is where competing vegetation rtops the seedlings.

Clearcuts may be planned in a variety of sizes and shapes. In past, clearcuts were large. This concentrated the logging, making greater efficiency and lower costs, and regeneration proved to be isfactory in most cases. The recent trend on National Forest land Alaska has been to reduce the size to 160 acres (65 ha) or less and ign the shape of the cutting boundary to blend with the landscape. s has been done in response to concern for esthetics and wildlife. the other hand, in Oregon where clearcuts or patch cuts have been ller, a recent trend has been to increase their size as skyline ging comes into greater use. This also helps to reduce distribution alder seed. In mixed stands, cutting units are now often made from ge to ridge.

Reducing the size of clearcuts increases costs because more road eage is needed to reach a given volume of timber. Smaller clearcuts e more perimeter per area cut than do larger ones, so risk of wind age around edges is increased. Also, there is less opportunity to ate cutting lines in windfirm locations.

Minimum clearcut size is influenced by the cost of road construction yarding. The cost of developing a landing and setting up yarding

equipment must be balanced against a considerable volume of logs to reduce the cost per thousand board feet. In Oregon and Washington, about 15 acres (6 ha) often is considered minimum clearcut size from this viewpoint; but logging costs vary widely with the type of equipment used.

Clearcuts may be arranged in a variety of ways. Problems with fire in Douglas-fir forests of Oregon and Washington led to the adoption of the patch cutting system where each clearcut was surrounded by green timber as a firebreak and seed source. This entailed building roads through uncut areas, thereby extending the road system more rapidly than with continuous clearcutting. Patch cutting was extended westward into hemlock-spruce stands with the same objectives in mind (Ruth and Silen 1950), although here fire danger was less and even large clearcuts regenerated well. Patch cutting in hemlock-spruce stands prevails in most areas today, but with less hesitancy in enlarging the size of a clearcut after the original cutover area has regenerated. Restrictions on size and shape of clearcuts come more from multiple-use objectives than from concern about regeneration.

Clearcutting favors spruce in the regenerating stand. Disturbance associated with clearcutting destroys much advance hemlock regeneration, taking away much of hemlock's initial advantage. A cutting area exposed to full sunlight favors the less tolerant and more seral spruce (Harris 1974, Berntsen 1955). Where Douglas-fir and red alder seed sources are available, clearcutting also favors these species. Site disturbance may be increased further by residue treatments such as broadcast burning and yarding unused material, thereby providing added advantage for seral species.

Clearcutting exposes the site to the sun, raises the temperature, speeds decomposition of raw humus, and thereby improves the productivity of the site. It is the preferred silvicultural system for stands infected with dwarf mistletoe, a problem discussed in detail in a later section.

Usually under the uncut timber stand there is a heavy mantle of humus and litter protecting the soil surface. Harvesting the timber disturbs part of this forest floor material and also adds large quantities of logging residue. Generally the soil is well protected. There are exceptions, such as main skidroads, landing areas, deep gorges, and steep shallow soil over bedrock where it is easy to scrape off the soil and deplete the site. Harvest cuttings can be designed to provide various levels of disturbance to a site. Disturbance must be limited to a level that provides adequate soil protection.

Clearcutting also has some disadvantages. It is less desirable esthetically than other harvesting systems. After clearcutting, several years elapse before the site is again fully utilized for timber production. Competing vegetation thrives in full sunlight and tends to take over the site more quickly than with the shelterwood or selection systems. This can be a serious problem if natural regeneration or planting fails, thereby permitting competing brush and red alder to get a head start. In swampy areas, clearcutting may reduce transpiration enough to cause an undesirable rise in the water table.

Harvesting logs does not seriously deplete the nutrient capital of hemlock-spruce ecosystems. Most of a tree's nutrients are in the

eaves, twigs, and roots, and these are left on the site (Journal of orestry 1952). Nutrients removed in the logs will be lost from the ite whatever the harvesting system, so except for some differences in iming, the loss does not enter into selection of the silvicultural ystem. Studies in other forest types have shown that some nutrients ay be carried away in streamflow and, should erosion occur, some will o with the soil that is lost. But, generally, the total loss of utrients is small relative to the nutrient capital stored in the oil or forest floor material.5/

Clearcutting is well adapted to harvest of old-growth stands. any old-growth trees are defective, often mistletoe infected, and rom the standpoint of timber management should be removed; but trying o remove only these trees would be difficult. Heavy equipment would e required and damage to the residual stand almost inevitable. eaving old-growth trees, even if sound, does not provide a good eturn on the capital investment in growing stock because growth is ow in proportion to tree volume. From the timber production stand- oint, it is best to clearcut old growth and start over with a vigorous oung stand (Harris 1974).

ONCLUSIONS

Clearcutting is recommended as the basic silvicultural system for emlock-spruce forests where timber production is the primary use. It eads to adequate natural regeneration and is economical; it thus eets two important objectives of timber harvesting. It is appropriate or old-growth stands with large and often defective timber--stands ccupying over 80 percent of the commercial forest in southeast laska. In fact, under projected harvesting schedules, the supply of ld growth in Alaska will outlast old growth in all other parts of the nited States. The hemlock-spruce forests of Alaska probably will be he last place where large equipment for logging and milling will be equired. With the long time period involved, it is important to arvest the most decadent stands first and to schedule the more thrifty tands for later harvest. Especially important in Alaska, clearcutting llows more solar radiation to reach the forest floor and thus increases iological decomposition of heavy organic accumulations. It is effec- ive in dwarf mistletoe control. It facilitates residue management nd fire protection. Through careful selection of equipment and arding techniques, clearcutting can provide a measure of control over ite disturbance and density of regeneration. Size, shape, and arrange- ent of clearcuts can be altered to reduce the visual effect of harvest utting.

Clearcutting permits longer cable yarding distances than would be racticable when yarding through standing timber. This reduces road ileage and costs, also soil and stream disturbance associated with oad construction. It leaves spacing of roads too wide, however, for hinning by cable during subsequent rotations.

Shelterwood and selection systems offer reasonable alternatives o clearcutting and should be used when clearcutting fails to meet

5/ The effects of clearcut harvesting on forest soils. A summary of major esearch. 25 p. Compiled by American Forest Institute, 1619 Massachusetts Ave., .W., Washington, D.C. 20036.

management objectives. The manager should identify objectives, evaluate alternatives, and prescribe the silvicultural system that best achieves the objectives. The prescription may be a classical textbook system. More likely, it will be a combination of several systems carefully prescribed to reach specific management goals.

SITE PREPARATION

Preparing the site for establishment of a new stand begins with removal of the mature stand. This provides an increase in available light, heat, and growing space for conifer regeneration and competing vegetation. The logging and yarding operation disturbs the soil, damages or destroys understory vegetation, and leaves behind unmerchantable forest residues. The timber harvesting operation provides opportunity for obtaining desired site preparation at low cost. On the other hand, if improperly done, the site can be damaged.

Depending on the intensity of management and ecological factors, managers may be willing to accept the site preparation as accomplished by timber harvest alone. Or they may expend considerable effort on further preparation of seed beds, treatment of residues, and control of competing vegetation.

An excellent review of site preparation methods for use in Oregon is available (Stewart 1978). In the following pages we will briefly discuss site preparation, noting important differences within the hemlock-spruce type.

RESIDUE MANAGEMENT

After clearcutting, forest residues, the unmerchantable organic material that remains, dominate the environment. Depending on circumstances, forest residues are a fire hazard, an obstruction to intensive management, a suitable seed bed for tree seedlings or an obstruction to their establishment, a source of essential nutrients, and a protective cover preventing soil erosion. Usually they are a combination of these.

Basic objectives of residue management are to protect the soil and its nutrient capital and streamflow and water quality and to provide for establishment of a new forest crop. Economic, esthetic, and recreational objectives must also be considered in choosing the most appropriate residue management alternatives.

For the reader interested in more detail than presented here, a state-of-knowledge review of forest residues management in hemlock-spruce forests has been published (Ruth and Harris 1975). A regional state-of-knowledge review of the various environmental effects of forest residues management for the primary forest types of the Pacific Northwest also is available (Cramer 1974).

Viewed just after logging, forest residues are the leftovers--standing dead trees, fallen trees, cull live trees, trees too small to harvest, tree tops, bark, branches, leaves, cones, and stumps.

The long term as well as immediate effects of residues should be evaluated in management decisions. Treatment alternatives must be carefully considered, and the best course of action determined. In some situations, no treatment at all may be the best course. This will be increasingly true as residue volumes continue to be reduced by improving utilization standards.

Forest residues are a physical obstruction to intensive management of the new stand. Cull logs, stumps, and piles of debris get in the way of workers and equipment during thinning and other cultural operations; some large residues persist until the next harvest cut. Obstructions make stand treatments more costly and may cause them to be deferred or rejected. The potential yield of the site, therefore, may not be fully realized. This problem is most acute after logging of defective old growth or stands with a high proportion of cedar (fig. 23)

Figure 23.--Logging slash remaining after clearcut logging of an old-growth hemlock-spruce stand with a high proportion of western redcedar. Cedar shake bolts have been salvaged. Olympic Peninsula, Washington.

Volume and Arrangement

Factors leading to high residue accumulation in hemlock-spruce ecosystems include high basic productivity of the species (Briegleb 1940; Fujimori 1971; Dimock 1958a, 1958b), infrequent wildfire, a preponderance of old-growth stands, and the cool climate and high

rainfall resulting in more humus and accumulation of organic debris on the forest floor (Gregory 1960). Productivity is more important southward, and lack of wildfire, old-growth stands, and slower decomposition rates are more important in the cooler northern parts of the range.

The volume and arrangement of residues vary, depending on the age and size of the timber stand that was harvested, its volume per acre, defect, structure, and species. Topography, logging method, utilization standards, contract requirements, market conditions, and the logger's skill also contribute. In Alaska and British Columbia where logs are rafted to the utilization plant, small logs and chunks may be left in the woods because they will escape from rafts and be lost.

Residue volume generally increases with stand age and successional development (Howard 1973). Vigorous, young stands contribute few cull logs that in old-growth stands add so much to residue (fig. 24). In the southern parts of the hemlock-spruce type, most stands that are harvested are young. Demand for logs is high, and economic conditions permit better utilization than farther north.

Figure 24.--Slash remaining after clearcut logging of 125-year-old hemlock-spruce with little defect--broadcast burning not planned. Oregon coast, 1973.

Timber volumes are lower in Alaska because of lower site quality; but stands being logged tend to be older and therefore more defective than in Oregon and Washington, so that total volume remaining as residue may equal that in the Pacific Northwest.

In Alaska, stands favored for harvest cutting have been the better, overmature, even-aged stands containing a high percentage of spruce. As logging shifts to more uneven-aged, near-climax stands, residue volume may increase (fig. 25). Offsetting this, as the value of wood increases, less will be left in the woods.

Figure 25.--Residue after harvesting of a near-climax hemlock-spruce stand, Thomas Bay, Alaska, 1972.

Utilization standards in hemlock-spruce forests have generally oved over the years. Early day loggers seldom took top logs less 30 in (76 cm) in diameter. Today 6 in (15 cm) is common, and a (10-cm) top is the rule on some ownerships. Also, more defective is being taken. Currently, there is a market in Oregon for ity logs with chippable content of 50 percent of the gross scale. ributing to this downward trend in logging residue in Oregon and ington is the increasing proportion of the annual cut in young ds with little defect, and periodic thinnings which remove defective s and reduce levels of growing stock.

The arrangement of forest residues is influenced by the logging od. High-lead yarding leaves numerous, narrow skid roads radiating the landing like the spokes of a wheel; disturbance increases rd the landing. Slash tends to be dragged into the landing with logs, producing a deep pile. Skid roads are narrow, have slash in depressions, and do not form adequate firelines.

Tractor yarding divides residues into sections bounded by skid s which are often quite adequate as firelines. This facilitates rol of wildfire but requires extra effort in setting fire for a cribed broadcast burn.

Grapple yarding in which at least one end of the logs is lifted of the ground disturbs residue less and leaves a more uniform

distribution than high-lead or tractor yarding. Skyline yarding in which logs are soon lifted free of the ground causes still less disturbance, leaving a quite uniform slash distribution (Ruth 1967b). Balloon yarding and helicopter yarding which essentially lift the logs directly upward cause the least disturbance.

In Oregon and Washington, red alder stands present a special residue management problem. The most common management objective is to convert alder forest to hemlock-fir, usually by clearcutting and planting. At rotation age, alder stands have much less biomass than conifer stands (Worthington et al. 1960), and residue volumes are correspondingly less. But alder characteristically has a rich understory of shrubs and herbs (Franklin and Pechanec 1968) which becomes part of the residue. The resulting tangle of logging slash and brush obstructs travel and interferes with planting operations. The brush overtops and suppresses conifer seedlings.

Treating Residues

The most common method of handling hemlock-spruce logging residues is to leave them untreated; that is, to utilize as much material as possible and leave the remainder to decay where it falls. This is least costly in current expense, but it may cost more in the long run. For example, in areas of appreciable fire danger, failure to treat residues can contribute to serious losses from wildfire.

Broadcast Burning

Broadcast burning has been the most common method of residue treatment in the southern portion of the hemlock-spruce range. Burning is less expensive than mechanical treatments and does not require heavy equipment that may expose and compact the soil. Use of fire is diminishing, however; and in recent years, pressures have been mounting for its elimination because of adverse effects of smoke. On the other hand, large residue accumulations increase risk of wildfire with uncontrolled smoke production. Controlled burning is still a treatment alternative that warrants careful consideration by forest managers.

The most obvious effect of residue disposal by broadcast burning is a sharp reduction in fire hazard. Many clearcut areas in Oregon and Washington have been burned for this purpose. Most needles, twigs, and material up to 3 in (8 cm) in diameter are consumed in a prescribed burn, but most larger material is consumed only in part (fig. 26) (Martin and Brackebusch 1974).

Without residue treatment, fire hazard in hemlock-spruce areas decreases gradually as needles drop off, fine materials decay or become compacted by winter snow, and growth of forest regeneration, brush, or hardwoods provides shade that keeps the litter moist.

In case of wildfire, unburned logging residues may offer so many obstacles that building a fireline in the face of spreading fire is impracticable. In this situation, a common procedure is to drop back to an area that offers less resistance--a truck or tractor road, stream, preestablished fireline, or an area of recently treated residue.

Figure 26.--Broadcast burning consumed almost all residue material up to about 3 in (8 cm) in diameter, leaving only the remains of larger logs as a continuing fire hazard, Siuslaw National Forest, Oregon. Divisions on stake indicate 1 ft (30 cm).

Strong arguments for burning develop when there are large accumu-
ations of residues, high fire danger, and the likelihood of poor
egeneration. This is most common in the southern portion of the
ange. Strong arguments against burning develop where fire danger is
ow. The obvious example is Alaska where harvested areas rarely dry
ut enough to burn. In Oregon and Washington, advocates of non
urning often are managing healthy young stands in areas where economic
onditions facilitate good utilization. They may be able to exclude
he public during periods of high fire danger. They often plan to
tilize advance regeneration present on harvested areas.

In general, the trend away from broadcast burning is likely to
ontinue. Unlike Douglas-fir and pine, hemlock and spruce have not
een dependent on fire for their perpetuation, and fire or similar
isturbance need not be an integral part of their ecology. Fire
hould not be eliminated but should be retained as a management
lternative and used when the benefits outweigh the detriments.
urning should be accomplished when smoke will flow away from sensi-
ive areas or be carried far aloft by strong convection currents.
ocal smoke management plans should be followed. A fast, hot fire
ollowed by prompt mopup is desirable.

Prescribed fire can become wildfire. The risk is low in coastal
orests, particularly where the residue area is surrounded by green
imber, but it does happen and the risk must be evaluated when
reatment of residue is considered. Where fire danger is high, the
reater risk may be to leave forest residues untreated.

In addition to reducing fire hazard, broadcast burning is useful
or reducing the volume of residue that interferes with establishment
f seedlings and intensive management of the new stand. It can also
e used to help control competition from unwanted plants. Effects on
oil will be discussed in a later section.

arding Unmerchantable Material

Yarding of unmerchantable material (YUM) is a contract requirement
n some public timber sales in Oregon and Washington. The requirement

is that, in addition to removing merchantable logs, all other woody material above specified dimensions, regardless of defect, be yarded to the landing. The dimensions usually specified are 8 in (20 cm) or larger on the large end and 10 ft (3 m) or more in length, but these may be adjusted to any size. YUM leads to improved utilization because once material is at the landing, more may profitably be hauled to a utilization plant. Thus YUM may be used not only to improve utilization but to control the amount and size of residues left on a harvested area. Ecological effects are similar to yarding additional merchantable logs. There is added damage to advanced regeneration, more exposure of mineral soil, reduced fire hazard, and more removal of nutrient capital. The area is opened for planting, and physical obstructions to thinning and other cultural treatments to the next crop are reduced.

Even though some of the defective material becomes merchantable after yarding to the landing and is removed from the site, huge piles of unusable material remain (fig. 27). If the residues are left

Figure 27.--A pile of hemlock-spruce forest residues yarded to the landing.

unburned, the area covered is taken out of production; if they are burned, the underlying soil may receive a "hard burn" according to the definition of Morris (1970). This is of limited consequence because the areas burned are small. Good survival and growth of planted seedlings have been noted on some of these burned areas. Burning is usually delayed until late in the season when surrounding residues are wet from fall rains and air pollution is less of a

YUM has not been required in Alaska or British Columbia, partly use small material tends to be lost from log rafts. It does r an opportunity to control the volume of residues in an environ- where treatment by burning often is not a viable alternative.

YUM yarding is expensive, reportedly sometimes over $400 per acre 000 per ha) in 1974 (Dowdle 1974). A positive benefit cost ratio s most likely where large volumes of cedar are present.

r Residue Treatments

Next to broadcast burning, the most common treatment is to burn heavy slash concentrations--at the landing, where the timber was icularly defective, or where residue has accumulated in depressions s. 28 and 29). Burning usually is accomplished during the first rains when spread of fire is unlikely.

Figure 28.--Photo taken before spot burning of residue concentrations, Oregon coast.

Piling of logging residues on clearcuts is sometimes done by tor in Oregon and Washington, usually on areas of high public use xtreme fire hazard. Piled residues usually are burned during ods of moist weather when fire is unlikely to spread. The piles be left unburned but they then become an obstacle in the way of nsive management of the next timber crop. Piling by tractor would estructive to most soils in Alaska and is not recommended for use e.

Figure 29.--Photo taken after spot burning of residue concentrations, Oregon coast.

Chipping is becoming increasingly common along roadsides. Unwanted vegetation and limbs trimmed from roadside trees are chipped, and the chips blown into small piles. This improves safety for drivers and the esthetic appearance of the roadside.

A layer of chips on the soil surface affects the nutrient status at the site by increasing the surface areas of the residues and thus speeding decay. This tends to tie up nitrogen in decay organisms and may temporarily limit tree growth (Cochran 1968). Not enough chipping has been done to fully evaluate the fire hazard of chips on the soil surface, although chips have been found to be a definite hazard along railroad rights-of-way (Jemisen and Lowden 1974).

Current Practice

Residue management is in transition in the hemlock-spruce type. Improvement in utilization, gradual over the years, has recently been more rapid. Greatest reductions in residue volumes have been near utilization plants where transportation costs are low. Other reductions come from careful felling and bucking to reduce breakage, cutting lower stumps, and utilizing to a smaller top diameter, handling logs more carefully, and using defective logs.

Increased attention is being given to short- and long-term effects of residues on stability and nutrition of soil. Timber harvesting and road construction are planned to keep residues out of streams. If residues fall into streams, they should be removed and placed above high-water level.

In Oregon and Washington, treatment of logging residues differs among forest landowners. Those who have heavy slash accumulations, summer drought conditions above average for the type, or a high proportion of western redcedar slash tend to favor burning. Others require yarding of unmerchantable material, then wait until late fall and burn the large concentrations at the landing. Still others forgo the added yarding cost for the unmerchantable material and burn the heavier concentrations at the landings and on the harvested area. Others leave the slash untreated.

Public land managers often are faced with increased fire risk because of heavy public use, and this tips the scale in favor of burning. Private landowners more often restrict use of their property during periods of extreme fire danger to reduce the risk of wildfire. Some strongly oppose burning of any kind. Often they have a nearby utilization plant and are able to remove smaller material from the area, thereby reducing residue volume.

Broadcast burning in coastal forests in Oregon and Washington may be done in the spring, summer, or autumn, most being done in the autumn during the drying period after rain. Burning in spring is less common than in summer because many areas remain too wet to burn. Some recent increases in spring burning have resulted from smoke management restrictions delaying autumn burning so the treatment is applied the following spring. Smoke management restriction also has provided some emphasis for summer burning which, until recently, was restricted mostly to wet areas with red alder residues.

Firelines are constructed around most slash areas in advance of burning, and water is made available for the more dangerous parts of the perimeter. The organic materials immediately outside the fireline often are wetted down before ignition. The various techniques used for burning are described in detail by Brown and Davis (1973).

Generally in Oregon and Washington, the trend is away from broadcast burning. Major contributing factors are the moist climate, presence of advance regeneration, better utilization, more harvest cuttings in young stands that have little defect, and smoke management restrictions. An increasingly common practice is to not burn at all or to restrict burning to the landing area and heavy slash concentrations. There are, however, heavily decayed, old-growth stands or open stands with dense brush understories where burning still appears to be a necessary treatment.

In British Columbia, residue management on all public and private forest land is prescribed by the British Columbia Forest Service following inspection of harvested areas (British Columbia Lumberman 1971). A guide to broadcast burning of logging slash is available for use where this treatment is prescribed (British Columbia Forest Service 1969). Currently some areas are broadcast burned, some are left unburned, and on some only the residue concentrations are burned. It is the

responsibility of the operator to carry out the prescribed treatment. The area must be released by the British Columbia Forest Service before adjacent timber can be logged. The prescription may require special measures to protect the soil, established seedlings, adjacent timber, or other property (British Columbia Lumberman 1969).

Snag falling is required as part of the hazard reduction program. Timber operators may elect to burn additional areas to improve access for planting or expose more mineral soil seed bed. Part of the road network is maintained after slash abatement to provide ready access in case of wildfire.

Logging operations are closed during critical fire weather. Improvements have been made in weather forecasts, training, and equipment for fighting fire (British Columbia Lumberman 1969). These changes and increasing public pressure against smoke in the atmosphere have resulted in a trend away from residue management by burning. The consensus of Canadian Forest Industries in 1971 was that about 30 percent of slash areas should be burned, although at that time the British Columbia Forest Service was requiring about 50 percent (British Columbia Lumberman 1971).

In coastal Alaska, most commercial forest land is still administered by the USDA Forest Service or the State of Alaska; the remainder is in small private ownerships. Logging residues on all forest lands essentially are left untreated.

Fire danger is usually low because of the cool, moist climate; and experience since pulp logging began in 1953 has shown the risk of wildfire in slash is not great enough to require treatment to reduce the hazard. Present Forest Service regulations limit the size of most clearcuts to 160 acres (65 ha). This disperses the slash hazard and reduces the probability of large fires.

Operators are required to maintain fire equipment on logging operations at all times and during occasional brief summer dry periods may be required to alter working hours or suspend operations.

Snag falling is required on National Forest lands where safety is a factor. Examples are where a falling snag could reach a road surface, rock pit, guyline, or equipment or where snags could interfere with helicopter yarding or fire control. All other snags are left for use by wildlife. This policy will doubtless be revised as more information is gained on the use and need of snags by various species of birds and mammals.

Most of the timber being logged in coastal Alaska is overmature, and defect is often high, resulting in large accumulations of residue. Public concern is mainly about esthetics and the apparent waste of raw material. Forest managers are also concerned about the obstruction to future management of young stands caused by large residues. Utilization standards are continuing to improve, and more defective material is being used for pulp. There may be some limited need for burning in the future, but the present trend toward better utilizatior and no burning appears likely to continue.

CONTROL OF COMPETING VEGETATION

Competition from unwanted vegetation can seriously impede regenera tion of conifers in the hemlock-spruce type. Understory vegetation is present under mature stands, especially the more open stands; and seral plants proliferate when the overstory is removed.

The problem is most acute in Oregon, where growing conditions are ideal and site productivity is high (fig. 30). The long growing season and relatively warm summers may result in complete cover of brush and tall annuals the year after logging. Unless this vegetation is controlled, adequate regeneration will be much delayed. The problem is acute on moist flats and on slopes, especially where the stand harvested was relatively open or intermixed with alder. Importan plant competitors include red alder, salmonberry, thimbleberry, vine maple, evergreen huckleberry, and salal.

Figure 30.--Sitka spruce seedling suppressed beneath dense salmonberry and thimbleberry. Cascade Head Experimental Forest, Oregon.

In British Columbia and Alaska, competing vegetation is most serious on alluvial flats, valley bottoms, and some moist slopes. Here, treatment to control salmonberry, thimbleberry and perhaps other species may be necessary.

Red alder becomes established readily after exposure of mineral soil and is an important competitor of conifers throughout the hemlock-spruce type. Although alder is an important tree species, it is considered an undesirable competitor of conifers in most situations. Red alder is a serious competitor primarily on alluvial streamside soils lacking a thick duff layer, and on upland sites where roadbuildir

or heavy disturbance of the surface organic layer has occurred during logging. The pattern of roadbuilding and logging is often apparent from the pattern of invading red alder (fig. 31).

Figure 31.--Alder invasion often follows excessive soil disturbance. The pattern of logging is apparent from alder establishment seen in this aerial view 10 years after clearcutting (Katlian Bay, Alaska).

Control of competing vegetation is attempted during two periods in the early development of stands: first, for site preparation during or immediately after timber harvest and before conifer regeneration has been established; second, to release conifers if they have been overtopped by faster growing vegetation. Strategies for control of competing vegetation differ in these two situations. In the first period there are no conifer seedlings to be protected; in the second, damage to conifers must be avoided.

Two basic approaches to brush control are to destroy brush plants or at least retard their growth and to speed establishment and growth of tree seedlings. Areas threatened by brush should be identified in advance of logging, brush control plans developed, and the logging operation designed to facilitate control work. For example, yarding may be arranged to drag logs through brush patches, thus destroying much of the aerial portions of the plants. Treetops may be felled into the brush and burned. These treatments tend to kill

brush plants back to ground level and clear the area for planting. After logging, additional mechanical, burning, and herbicide treatments may be needed.

Mechanical

Mechanical scarification with tractors and tractor-drawn equipment may be useful in some situations in the hemlock-spruce type, although the method has serious limitations. Tractors cannot operate safely on steep slopes, and soil disturbance can lead to erosion and mass-wasting.

Care must be taken to avoid soil erosion and stream siltation that can damage fish habitat. Although scarification may retard or destroy existing brush plants, it may create ideal conditions for invasion by red alder. On youthful soils in Alaska, scalping of the surface organic layer may slow subsequent growth rate of conifers.

Prescribed Burning

Broadcast burning can be used in site preparation to reduce vegetative competition for light, water, and nutrients. In Oregon and Washington, burning may be prescribed almost solely for vegetative control, with reduction in logging residues only an incidental result. Many old-growth stands have low volumes per acre, heavy underbrush, and only scattered regeneration in the understory. Clearcutting without burning perpetuates the brush, which in turn prevents establishment of new seedlings. In Oregon, broadcast burning may be used successfully to control salal and evergreen huckleberry in site preparation. Although resprouting occurs, these plants may be set back enough to allow planted conifers to gain dominance.

Herbicides

Herbicides are used in regeneration work in Oregon and Washington either to prepare sites for reforestation or to release existing seedlings from competing vegetation. It is not necessary to kill all competing vegetation, only to set it back to where it offers less competition to conifers (Gratkowski 1975). More complete control of competitive vegetation is needed for site preparation than for release of existing seedlings.

Herbicides are often used in conjunction with broadcast burning. In the past, some clearcut areas in Oregon and Washington were left untreated and regenerated with a mixture of species. Almost always this included red alder, a few hemlock and spruce, and perhaps other conifers, plus lots of brush, both under the alder and in thickets. Many such areas are now being rehabilitated by an alder conversion operation (Dimock et al. 1976a). A common approach is high-lead logging to remove merchantable logs and to knock down brush and unmerchantable alder; broadcast burning, prompt planting, and herbicide spraying as needed. A brown and burn technique is often used. Herbicide is applied to kill leaves and thereby desiccate green vegetation. A treated area must be burned within a few weeks before vegetation greens up again (Hurley and Taylor 1974).

mention specific chemicals and application rates, we will refer to current literature and caution the reader to read this and subsequent literature that becomes available. The advice of competent specialists should be sought and the latest regulations consulted before herbicides are applied.

Considerable information is available on application and effectiven of herbicides on salmonberry, red alder, and other species the land manager may wish to control on hemlock-spruce sites (Krygier and Ruth 1961; Gratkowski 1971; Stewart 1974a, 1974b). The season of application is important (Gratkowski 1971). So is the formulation of the herbicide (Gratkowski 1975). For example, the iso-octyl ester of 2,4-D ((2,4-dichlorophenoxy) acetic acid) has been found to cause far less mortality to salmonids than the butyl or PGBE (propylene glycol butyl ether) esters (Meehan et al. 1974). Several summary publications contain information particularly applicable to hemlock-spru sites (Gratkowski 1967, 1975; Stewart 1978).

The shelterwood system of harvest cutting offers a means of accomplishing alder control and favoring hemlock. Theoretically, enough overstory may be left to shade out alder, then the overstory removed after hemlock is well established. This system, however, has been little used because of economics and because in Oregon and Washington many land managers want at least some Douglas-fir in the regenerating stand.

In Alaska, primary competition is from red alder and salmonberry (Harris 1967). Almost no herbicides have been applied, but new regulations for National Forests require immediate regeneration of all cutover land and are prompting a reevaluation of regeneration practices. Site preparation, including control of unwanted vegetation along with immediate planting, appears necessary to meet management objectives on affected sites.

Most problem sites are adjacent to salmon spawning and rearing streams and tributaries where fishery values are high. Consequently, great care must be taken to assure that site preparation will not damage fish habitat. Any future use of chemicals will require careful evaluation to assure that there is no reduction in water quality or damage to aquatic organisms.

REGENERATION

The regeneration method for a particular area should be selected not as an individual item but in connection with a silvicultural system that makes the best compromise between management objectives, environmental factors, and costs. The land manager must select the basic harvest cutting system and plan the residue management, the site preparation, and the seeding, planting, and control of competition that may be needed.

Regeneration planning, often stratified by entire clearcut units, should be more detailed and provide for varying treatments within units. Thus, a particular clearcut may be partly overstocked

ith advance regeneration that needs thinning, have an area needing esidue treatment to expose suitable microsites for planting, and ave brush patches where control of competition and planting of arge seedlings are needed. In the regeneration prescription the anager should specify the species, type, age, size, and condition of lanting stock and should carefully match the seedlings to the ariable site conditions in the field. Plans should be made in dvance of harvest cutting to allow time for producing the planting tock but should be kept flexible to meet changing field conditions.

EED

Genetics and Selection

Compared with knowledge of other conifers, little is known about enetic variation in western hemlock and Sitka spruce. Variations in itka spruce have been described by Burley (1966), Daubenmire (1968), ollard et al. (1975). Information on the genetics of Sitka spruce as recently been reviewed (Roche and Fowler 1975; Harris, in press). rovenance research in western hemlock is underway by the British orestry Commission (Piesch 1974), and existing information indicates hat the species is well suited to genetic improvement efforts (Piesch 974, 1976).

For natural regeneration, seed from adjacent stands or occasionally rom residual trees are depended on to regenerate clearcut areas. his is generally accepted practice with most species, including emlock and spruce. With artificial regeneration, the land manager hould be sure the seed source is genetically adapted to the area eing regenerated; this is best done by selecting seed of local origin.

Within a local seed source, individual trees vary genetically in rowth rate, timber quality, and other characteristics that affect ree value. Substantial genetic gains may be made by using seed from rees having desirable characteristics. Always there is a risk that elected trees are lacking in less obvious characteristics, such as rought resistance, frost hardiness, and insect or disease resistance. election on the basis of specific characteristics has the potential or reducing the genetic base of the regenerated forest. With our resent limited knowledge, replacing the original gene pool with an improved" strain could turn out many years later to have been a ostly mistake. In deciding on a genetic tree improvement program, he forest manager would be well advised to take a cautious approach hat will maintain genetic diversity (Silen 1976).

Seed Collection

Most western hemlock and Sitka spruce cones are picked from tanding or recently felled forest trees or collected from squirrel aches. Many cones can be obtained from trees recently cut by elling crews, but there is limited opportunity to collect from the est trees.

When local seed are not available, care must be taken that seed rom a suitable source are used. As a broad guide, seed collection ones have been established within the hemlock-spruce type in Oregon

and Washington (Western Forest Tree Seed Council 1973) and in British Columbia (Dobbs et al. 1976); zones are being developed for Alaska.

When possible, it is desirable to select superior trees or stands, reserve them from cutting, and collect cones from them repeatedly as needed and as cone crops occur. This approach involves climbing or otherwise gaining access to the crowns of tall trees. Collection techniques using ladders, hydraulic platforms, climbing gear, and tree nets are described by (Eversole (1954), Seal et al. (1955), and Hutt (1957).

Cones should be collected during late September and early October. The cutoff point is when seed fall begins, usually the latter part of October (Ruth and Berntsen 1955, Harris 1969). The earliest date for collection varies by species. Harris (1969) studied the 1966 seed crop near Juneau, Alaska, and found that spruce seed ripened about 3 weeks earlier than hemlock, reaching maximum viability by September 3. Hemlock viability was still low on September 3 but increased rapidly the week of September 10, then continued to increase slowly through the final collection on October 16. As spruce cones ripen, their color changes from light yellow green to yellow red (Safford 1974). As hemlock cones ripen, their color changes from green with purple tips to brown with red-brown tips (Harris 1969).

Hemlock and spruce cones awaiting seed extraction are usually stored in loosely filled permeable sacks in opensided cone drying sheds. Ample air circulation is needed around each sack to minimize heating and buildup of mold. Green cones should be surface dried before storage. An excellent guide to collecting cones of important conifers in the hemlock-spruce type is available (Dobbs et al. 1976).

Seed Extraction

Seed extraction procedures for hemlock and spruce cones follow those for most conifers--air drying or kiln drying to open cone scales and tumbling to extract the seed. Kiln temperatures usually are set at 90° to 110°F (32° to 43°C); drying time is 2 to 48 hours, depending on moisture content of the cones.

Extracted seed are cleaned by screening out cone scales, dirt, and debris; dewinging; and fanning to remove wings, hollow seeds, and dust.

Seeds of most trees within the hemlock-spruce type are small (Schopmeyer 1974) (table 4). They are light and easily damaged and must be processed carefully.

Seed Storage

Several years can elapse between bumper seed crops, so annual planting and seeding programs depend on successful storage of seed. Seed of both hemlock and Sitka spruce keep best below the freezing point; generally seed are stored at 0°F (-18°C). Barton (1954) showed that viability was maintained better at this temperature than at 12°F (-11°C) or 25°F (-4°C); distinct differences showed up after

Table 4--Cleaned seeds per pound of common tree species within the hemlock-spruce type[1/]

Species	Number of seeds per pound (kg)	
	Average	Range
Western hemlock	260,000 (573 000)	189,000-508,000 (417 000)-(1 120 000)
Sitka spruce	210,000 (463 000)	155,000-400,000 (342 000)-(882 000)
Douglas-fir	39,000 (86 000)	29,000-46,000 (64 000)-(101 000)
Western redcedar	414,000 (913 000)	203,000-593,000 (448 000)-(1 308 000)
Red alder	666,000 (1 468 000)	383,000-1,087,000 (844 000)-(2 397 000)

[1/] Schopmeyer (1974).

years of storage. Maintenance of viability can be expected for at ast 5 years, and this generally bridges the gap between large seed ops. Lavender (1956) demonstrated that temperatures and humidities perienced between removal of hemlock seeds from storage and testing seeding do not appreciably reduce viability.

Pregermination Treatments

Stratification of western hemlock seed increases rate of germination t has only minor effect on total germination (Bientjes 1954, Ching 1958, szewicz and Holmes 1961, Edwards 1973). Seed stratified for 3 weeks 33°F (1°C) germinated faster than untreated seeds. Longer stratifi- tion periods caused additional but smaller increases in rate. ratified seed also germinate more uniformly. For example, germination tes between unstratified seed lots varied by 8.6 days in the time reach 50-percent germination, whereas seed lots stratified for weeks varied by only 3.6 days (Edwards 1973). Fast germination duces the length of a critical survival period for the seedling. iform germination also simplifies nursery operation and reduces riation in seedling size. Seeds usually are stratified by presoaking least 24 hours at room temperature, then are drained and placed in cold room at 34° to 41°F (1° to 5°C).

Seed Testing

Official rules for testing viability are to place seed on a otter or in a petri dish. For hemlock, temperature should be intained at 68°F (20°C) for 28 days and the seed exposed to at

least an 8-hour photoperiod. Recent research, however, has shown that maximum germination rate and value occur with a 4-hour photoperiod. An 8-hour photoperiod resulted in a slower germination rate, about the same as in total darkness, but 16- to 24-hour photoperiods significantly depressed germination rates (Edwards and Olsen 1973).

For spruce, the rules call for alternating temperatures of 68°F and 86°F (20°C and 30°C) for 21 days. A photoperiod should be supplied, and more than 8 hours may benefit some seed lots. Stratification prior to testing is not required for either hemlock or spruce (Association of Official Seed Analysts 1970).

NATURAL REGENERATION

Seed Production and Dissemination

Western hemlock and Sitka spruce seed production generally is adequate for establishment of regeneration even on large clearcuts, so few areas fail to regenerate from lack of seed (Harris 1967, Ruth and Berntsen 1955). Failures more often are due to competing vegetation and can be aggravated by occasional seed crop failures that give the competition a head start on tree seedlings.

Natural regeneration after clearcutting is influenced by direction of seed dissemination. Hemlock and spruce cones tend to open and seed to disseminate during periods of dry weather (Harris 1969). After cones mature in the autumn, cone scales open and close in response to dry and wet atmospheric conditions with much flexing of cone scales during the season. Dry winds along the coast normally blow from the north and east, causing cones to open and seed to disseminate south to west. Winds suddenly switch direction as low pressure areas approach. Toward the south this shift is to the southwest, in Alaska to the southeast. There is a lag period before cone scales are closed in response to the higher humidity, so some seed are disseminated northerly. These may be storm winds that carry seed considerable distances. One season was noted in coastal Oregon when no dry periods occurred after October seed maturation. This eliminated that burst of seed fall expected with the first northeast wind. Seed fall stretched over a long period, and dissemination was northeasterly. Usually, dry winds do occur and a seed source located on the northerly side of a clearcut probably is more effective than one on another side.

Rate of fall of hemlock seed is 2.6 ft (8 m) per second and spruce 3.1 ft (0.9 m). This compares with 4.4 ft (1.3 m) for Douglas-fi 4.95 ft (1.5 m) for Pacific silver fir, and 5.1 ft (1.6 m) for western redcedar (Siggins 1933), so hemlock and spruce seed should reach farther out into clearcut areas than these associates.

Seeding Establishment

Western hemlock and Sitka spruce seed will germinate and seedlings will grow on a variety of seed beds. It is the adverse factors of the environment that limit seedling establishment. These include drought, frost heaving, surface heat, flooding, animal damage, and

competition from neighboring plants. We will discuss "mineral soil" and "organic" seed beds.

Organic seed beds are generally considered to be the surface organic layers; the litter, fermentation, and humus layers, including rotten wood. Mineral soils are generally considered to be the A2, B, and C horizons. Soil material, when mixed and not in the context of horizons, is arbitrarily considered to be organic soil if it contains at least 12-20 percent organic carbon, depending on clay content (USDA Soil Conservation Service 1975). Soil containing less organic carbon than this is mineral soil.

In Alaska hemlock and spruce will germinate on both organic and mineral soil seed beds. Establishment and subsequent growth, however, is much better on soils with a high percentage of organic material. Nitrogen and mineral nutrient element content are far higher than in mineral horizons below (Heilman and Gass 1974). Mineral soils stripped of surface organic material may be unsuitable seed beds because underlying soil horizons contain few nutrients to support growth. It does not follow, however, that logging should always minimize surface disturbance. Logging practices usually do not remove surface horizons over large contiguous areas. Disturbance tends to be patchy. Mineral soil horizons are exposed when moving logs scrape furrows. Stumps are uprooted when logs hang up and tear them out, exposing mineral soil. Logs tend to slide over residue accumulations without disturbance to underlying ground surface but gouge or scrape the surface briefly when they pass beyond. Ground surface is often irregular; moving logs tend to gouge protruding hummocks but pass over low spots. Thus, productive surface horizons may be removed, piled deeper, or mixed with lower horizons.

Shade affects suitability of seed beds. Minore (1972) found that both duff-covered soil and rotten wood were good seed beds under shade but neither were suitable under full sunlight. Preserving duff accumulation under shaded conditions benefited growth of all conifer species tested.

Suitability of organic seed beds versus mineral soil seed beds varies with latitude, exposure, and the extent of the seed bed. In Alaska, most seed beds are organic and that is where most seedlings become established, both in light to moderate shade or in the open. Mineral soil seed beds may be suitable if their extent is limited, but nutrition soon becomes a problem. Southward in Oregon and Washington, exposed organic matter is more likely to dry out in the sun so that a seedling's radicle is killed before it can penetrate to available moisture. Sometimes the radicle will make initial penetration during wet weather, only to have a dry spell cause organic material to dry downward so fast that the radicle cannot keep up with receding moisture. A few sunny days during the germination period can cause heavy seedling mortality (Ruth 1967a). On the other hand, soils are better developed than in Alaska and nutrients are available in lower soil horizons to support good tree growth.

On exposed organic seed beds, lethal surface temperatures may kill the seedlings. The surface of a dry seed bed exposed to full sun may reach temperatures above 150°F (66°C), depending on moisture, exposure time, and sun angle. Organic material, being a poor conductor, cannot conduct heat downward as well as a mineral soil can. It

becomes hotter and more seedlings are killed than on mineral soil seed beds. Toward the south, exposed organic seed beds become less and less hospitable for seedling establishment, until few seedlings establish on organic seed beds on clearcuts.

Type of seed bed also affects species composition. Douglas-fir and red alder prefer mineral soil seed beds, so increasing the organic content of seed beds favors hemlock and spruce over the more seral species.

Where moisture or temperature are limiting, shade improves seedling establishment. Even a small object shading the lower quarter inch (6 mm) of a seedling stem may prevent lethal seed bed surface temperatures. Thus, a rough soil surface is more favorable for seedlings than a smooth one. Herbs and shrubs reduce surface temperatures. Live vegetation uses soil moisture, but generally this does not overcome beneficial effects of shade. The surface layer that is so important for initial seedling establishment retains more moisture in the shade than in the open.

On the other hand, shade can be dense enough to prevent seedling establishment; for example, dense, young hemlock-spruce stands at the sapling stage are almost devoid of understory vegetation, including tree seedlings. Salmonberry and thimbleberry thickets also provide heavy shade in the summer, and autumn leaf fall smothers most seedlings that survive the shade.

Organic seed beds that remain cool and moist enough for seedling establishment have the advantage that few plants other than hemlock and spruce will grow on them. Thus, the tree seedlings have little competition for moisture and nutrients. When only occasional seedlings are found in brush areas, almost invariably they are growing on rotten wood.

The excellent regeneration obtained on Oregon clearcuts generally occurs when the microsite is shaded in some way--by logging slash, vegetation, or perhaps by no more than an irregularity in the surface that shades individual seeds during germination. Seedlings also may get started during a wet spring that gives them time for root growth to keep up with receding moisture levels when dry weather arrives. Less shade is needed to the north because dry periods are less common.

Hemlock and spruce seedlings often invade openings dominated by other vegetation by becoming established on logs that have fallen into the opening from an adjacent timber stand (Davidson 1967).

Western hemlock and Sitka spruce seed remain viable on the forest floor over winter and germinate the following spring. Seed failing to germinate does not hold over to future years (Isaac 1940).

The effectiveness of natural seed fall or artificially sown seed can be increased by poisoning rodents on the area to be regenerated. Hemlock and spruce usually are prolific enough that this is unnecessary. Many poisons have been banned because of the undesirability of introducing them into the food chain.

Effects of Forest Residues on Seedling Establishment

Harvest cuttings and the resulting residue accumulation should leave an environment suitable for establishing a new timber stand. Fresh logging residues are unsatisfactory seed beds (fig. 32); but after decay is well advanced, the radicle from a germinating seed can penetrate the surface and the decaying wood provides adequate nutrition for seedling survival and growth (Morris 1958, 1970). Litter that covers the surface further improves the seed bed and may speed decay of the underlying wood. In contrast to hemlock and spruce, Douglas-fir and red alder seldom become established on rotten wood.

Figure 32.--Five years after logging and seeding, this seed bed of logging residue remained nonstocked. Note residual hemlock seedlings nearby. Maybeso Experimental Forest, Alaska.

Logging residues intercept natural seed fall or aerially sown seed. They cover mineral soil seed beds, obstruct the movement of planting crews, and make impractical the maintenance of a specified spacing of planted trees. Slash accumulations contribute to the clumped tree distribution often apparent in young hemlock-spruce stands. Slash-caused openings tend to seed in eventually but the delay retards stand development, causing variation in height and age in the new stand. On the other hand, partial shade provided by moderate amounts of logging slash improved early survival of spruce and hemlock on mineral soil during an abnormally dry summer in Alaska (Harris 1967).

Forest residues affect tree seedlings in several incidental ways. Bark may slough off a log or stump and cover nearby seedlings. Some seedlings become established under logs or large limbs, only to have the leader grow up into these logs or limbs and be damaged or grow around them, causing a deformity. Sometimes residues settle to the ground and crush seedlings. Other seedlings are damaged as their leaders sway in the wind and rub against residues. Residues tend to creep downslope under the weight of a heavy snowpack and destroy small seedlings in their path.

Residues also limit access to tree seedlings by cattle and big game, thereby reducing browsing damage. On the other hand, they provide shelter for the small mammals that damage seedlings.

Where frost damage is a problem, forest residues intercept outgoing long-wave radiation and tend to slow nighttime cooling. They also slow cold air drainage. The net effect is variable.

In Alaska, Harris and Farr (1974) noted that on alluvial streamside sites subject to flooding, Sitka spruce and western hemlock seedlings become established alongside stumps or atop decayed logs or debris and thus avoid the intermittent high water.

The foregoing relationships between hemlock-spruce forest residues and tree seedlings can be used to influence seedling establishment. The major concerns are to speed seedling establishment, improve spacing, and control species composition. Residue management affects all of these.

Mechanical removal of residue will increase disturbance of the area and expose more mineral soil. In the southern hemlock-spruce range additional exposure may be obtained by broadcast burning.

Control of Advance Regeneration

When hemlock and spruce seedlings are in the understory prior to harvest cutting, the overstory removal cut can provide some stocking control. Overstocking can be reduced by yarding systems, such as high-lead, that cause considerable ground disturbance. Conversely, needed regeneration can be protected by skyline yarding systems that lift logs free of the ground.

A high level of disturbance destroys most advance regeneration and delays seedling establishment until new seedlings germinate or are planted. Logging disturbance also is useful when a different species or genetically superior stock is to be planted. Usually advance regeneration is hemlock, and disturbance facilitates establishing a mixture of spruce or Douglas-fir by natural regeneration, seeding, or planting. Toward the south mineral soil deliberately may be exposed to provide seed beds or planting sites. Anywhere in the type, disturbance will increase the chance for alder invasion if a seed source is present.

Broadcast burning destroys most advance regeneration and, unless the area is planted or seeded, delays seedling establishment until after the next seed crop. This may be several years, and burned areas are routinely planted to avoid risking this delay.

Since burning destroys most advance regeneration, burned areas nitially have fewer seedlings than unburned areas do, and seedlings ay be better distributed (Harris 1966). But where burning exposes dditional seed beds, the potential for subsequent regeneration may e greater than without burning (Berntsen 1955, Gockerell 1966, etherington 1965).

Harris (1966) found spruce seedling establishment was better and emlock poorer on a burned compared with an unburned area, indicating hat burning might be used to increase the proportion of spruce. his is consistent with Sitka spruce's role as a more seral tree pecies than western hemlock.

A decision to save advance regeneration insures that logging esidues will be intermixed with the tree seedlings and compounds the ifficulties of treating residues. Trials of the shelterwood system n southern hemlock-spruce forests emphasize the difficulties. learcutting with protection of advance regeneration produces all the ogging residue at one time. On the other hand, a seed cut and one r more removal cuts create residues over a span of several years, ith time for some decay to take place between cuts. A decision of hether or not to treat residues should be made prior to each cut.

LANTING

More western hemlock and Sitka spruce are being planted. omplacent feelings about hemlock-spruce regeneration are changing to sense of urgency. Supplies of old growth are exhausted on many rivate ownerships in Oregon and Washington, and survival of utilization lants now depends on rapid establishment and growth of young stands. he National Forest Management Act of 1976 (U.S. Laws, Statutes, etc. 976) requires rapid restocking of cutover National Forest lands. ith a short rotation, a 5-year delay in regeneration can mean about 0-percent reduction in wood supply. Greatly increased land and tumpage values make it costly to expand land ownership or purchase ogs on the open market. It is important then that each acre designated or timber production be promptly and adequately stocked with desirable rees. Gains in timber production through tree improvement programs re possible, and this requires planting superior seedlings and the bility to propagate them.

In Alaska, there is far less emphasis on planting and seeding han in Washington and Oregon and natural regeneration is the primary eans of restocking cutover land; however changes are coming. Problem ituations have been defined, container planting stock is being roduced and planted, and pilot attempts have been made to control ompeting vegetation.

A common goal is to have every acre successfully regenerated ithin 1 year of clearcutting. The planting of highly productive sites o speed stand establishment and shorten the rotation has become tandard practice on some ownerships. Planting is often used to mprove species composition. Control of competing vegetation usually s an important part of the regeneration process.

Production of Planting Stock

Production of western hemlock and Sitka spruce planting stock is currently undergoing rapid change as containerized seedlings are used as well as the traditional bare-root seedlings. Growing seedlings in containers under controlled conditions is an advantage for these small-seeded species because germination and initial establishment have been a problem in outdoor nursery beds. The demand for bare-root hemlock seedlings generally has exceeded the supply, so for some landowners the several nurseries now producing containerized hemlock seedlings provide their first opportunity for planting this species without resorting to wild seedlings found in the forest.

Information is available on production of bare-root seedlings in forest nurseries (Aldhous 1972, van den Driessche 1969, Armson and Sadreika 1974).

Western hemlock and Sitka spruce seedlings are difficult to grow in outdoor nursery beds. Their small size makes them particularly susceptible to frost heaving in cold weather and to heat damage in warm weather. Seed beds may need screening to protect seeds from birds and rodents. Nursery production has been low compared with other Pacific Northwest species, and nursery practices are not fully worked out (Ruth 1974, Long and Winjum 1974).

A recent approach is to grow bare-root seedlings in nursery bed-houses. Seeds can be sown as early as February and large transplant seedlings produced in 2 years (Cowles 1976). Production of rooted cuttings is also being investigated (Boyd 1976). Research with containerized seedlings is providing basic information applicable as well to production of bare-root stock (Stein 1974).

Container-grown seedlings are being used at an increasing rate in reforestation in the West (Stein and Owston 1977). In recent years, the technology of producing seedlings in containers has undergone rapid development; and the technology used today for production of container-grown seedlings has been well described (Sjoberg and Matthews 1977, Tanaka and Triebwasser 1976, Tinus et al. 1974, Stein and Owston 1977, Cleary et al. 1978). Facilities range from simple shade frames to elaborate greenhouses (fig. 33). Some facilities are equipped with supplemental lighting. Within these, seedlings are grown in a variety of plastic containers (Tinus et al. 1974).

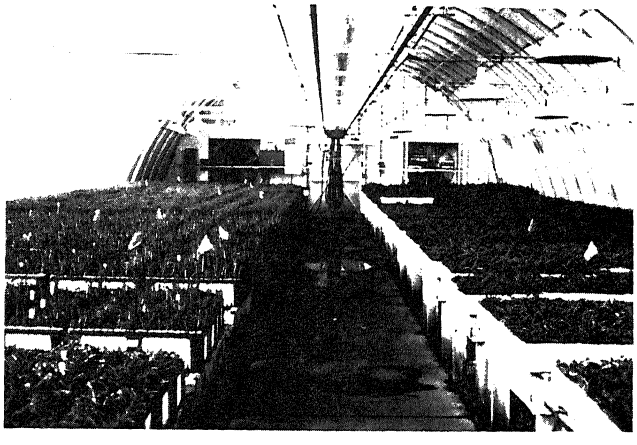

Figure 33.--The technology of containerized seedling production is undergoing rapid change. Western hemlock and Sitka spruce seedlings are being grown in this experimental greenhouse located at Beaver Creek, Oregon.

A container system provides opportunities to manipulate the environment and regulate development of seedlings. For example, bud set may be induced by reducing water, withholding nitrogen, and shortening the photoperiod. Growth can be extended into the fall by prolonging the photoperiod (Cleary et al. 1978).

Potential advantages of using container-grown stock over bare-root stock include: faster production and more flexible growing schedules, reduced root disturbance and less planting shock, extended planting seasons, easier planting on adverse sites, and higher quality of hemlock and spruce seedlings.

Potential disadvantages include: higher costs of production and transportation, generally smaller seedlings, and tendency for abnormal root growth and frost heaving.

In Alaska propagation of seedlings is still in the experimental stage; emphasis is on container production in greenhouses. Container production appears to be more feasible than bare-root production in nurseries because of the cool summer temperatures, high rainfall, short growing season, and the lack of suitable nursery sites. Growing seedlings from Alaska seed sources at established facilities in States farther south does not appear feasible now. In addition to high transportation costs, there are problems with seedling growth. Trees from high latitudes become dormant under the shorter photoperiod and growth cannot be maintained[6/] (fig. 34). Hemlock and spruce seedlings

Figure 34.--Four-month-old Sitka spruce seedlings, Juneau, Alaska, provenance: Right, grown under normal day length for latitude of provenance (58°18'N.); left, grown under day length for latitude 48°50'N.

6/ Personal communication from Richard W. Tinus, Principal Plant Physiologist, USDA Forest Service Shelterbelt Laboratory, Bottineau, N.D.

from Alaska sources cannot be grown successfully at lower latitudes unless the photoperiod is extended, and most available nurseries do not control photoperiod.

Handling, Storage, and Transportation

The time between removal from the nursery or greenhouse and planting is critical for seedlings. For bare-root stock, this period is probably more critical than for container stock, as roots are more exposed to environmental stress. Extremes of heat, cold, and drought are especially damaging.

Hemlock and spruce seedlings require careful handling to insure good survival. Care should be taken that roots are not exposed to drying conditions and seedlings are protected from extremes of temperatures. Seedlings should be dormant during storage, handling, shipping, and planting. An excellent source of more detailed information and references has been provided by Cleary et al. (1978). In general, environmental stress caused by warm, dry conditions is more important toward the south. Costs and logistics of truck, boat, and air transportation are of more concern toward the north.

Planting Guidelines

Much of the information available for other forest types is applicable to hemlock-spruce. An excellent overview of current practices used in Oregon has been provided by Greaves and Hermann (1978).

Hand planting is required in virtually all situations throughout the type. Hillsides usually are too steep for machine planting, and flat bottom land is too wet. Also, in most areas where old-growth stands are logged, heavy logging residues create obstacles to machine planting whether or not broadcast burning is done.

Several field experiments comparing container and bare-root planting stock have been established. In Oregon and Washington, early results indicated no significant difference in survival rates between the two kinds of planting stock (Gutzwiler and Winjum 1974). In contrast, Arnott's (1976) results from low-, medium-, and high-elevation hemlock plantations in British Columbia showed that container-grown seedlings survived better than bare-root seedlings, but growth rates were about the same.

For any planting stock, successful survival in the field depends heavily on a seedling's ability to withstand moisture stress. Bigger and better seedlings will help, whether containerized or bare root; but seedling quality seldom makes up for poor preparation of the site. Generally, it is better to apply such measures as treating logging residues and reducing competing vegetation than to try to solve problems by selection of planting stock. Both site preparation and the best planting stock are usually needed to achieve successful regeneration of problem areas. In addition, where animal damage is a problem, special measures may be necessary to protect seedlings (see page 107).

DIRECT SEEDING

With natural hemlock and spruce seed fall generally adequate, direct seeding has been confined to special situations. These include seeding to supplement a poor seed crop or replace a seed crop failure, to increase the proportion of a particular species in the new stand, to regenerate inaccessible areas where planting costs would be excessive, and to reforest large burns or other areas left without a natural seed source. Direct seeding is not a satisfactory method of combating regeneration failures caused by competing vegetation. Early growth of seedlings is slow and they are readily overtopped.

Direct seeding trials have met with some success but with frequent failure (Shaw 1953, Harris 1965). An important problem was seed losses to rodents. Losses can be greatly reduced through use of rodent control chemicals, either on the seed itself or by baiting the area prior to seeding (Carmichael and Dick 1956); but restrictions on use of poisons have largely eliminated this practice. It should be possible to improve seedling establishment by reviving the old technique of sowing an excess of seed. For example, Isaac (1939) found that a satisfactory stand of Sitka spruce could be established by broadcast seeding at the rate of 1 or 2 lb/acre (1.1-2.2 kg/ha) of seed if seeding was done within 2 years after a slash burn. This approach seems appropriate in areas with low rodent populations or where planting is impractical. But, in general, the inability to use rodent control chemicals, high cost of seeds, and development of new nursery and planting techniques have tipped the scales in favor of planting as the best artificial regeneration method.

THINNING

Thinning is the systematic regulation of growing stock in a young forest (Malmberg 1965). Trees are removed in young stands to stimulate growth of the remaining trees and to increase financial return. This is accomplished by removing and utilizing trees that otherwise would be crowded out of the stand and lost, and by concentrating growth on fewer, larger, and physiologically more efficient trees. Thinnings may also be made to control species composition, improve windfirmness, increase forage, or for esthetics, recreation, or other purposes. Following a thinning, the openings made in the canopy should be closed by growth of the remaining trees. Objectives of a thinning should be clearly defined and silvicultural prescriptions written accordingly. The emphasis in this section is on management of young stands for increased financial return.

Young hemlock-spruce stands vary in stocking, but understocking is rare. Most, having originated from prolific natural seed fall, are overstocked. Trees that reach harvestable size, having undergone intense competition, are smaller than had they been released from competition by early thinnings.

Thinnings may be characterized in several ways. Under *stocking control*, also called precommercial thinning or spacing, most of the cut trees are left on the site, and the operation requires a financial investment by the landowner or manager. *Commercial thinning* pays its own way through sale of trees taken from the stand. *Thinning intensity* refers to the volume of trees removed from the stand. It may be expressed as

a percent of the total stand volume. Often it is expressed as an annual thinning yield--the volume removed in a thinning divided by the number of years since the last thinning. Expressed this way, thinning yields may be compared between stands regardless of the length of the thinning cycle.

Type of thinning refers to the dominance class or quality of trees removed from the stand. A *low thinning* removes trees predominantly from the lower canopy; a *crown thinning* takes trees from the upper canopy. A *selection thinning* removes dominant trees to stimulate growth in lower crown classes. In a *mechanical thinning* trees are taken predominantly on the basis of a predetermined spacing. A *free or combination thinning* is a combination of methods (Smith 1962). For additional terminology pertaining to thinning, see Ford-Robertson (1971).

Thinning decisions are based on both silvicultural and economic considerations. Silviculturally, thinning should provide improved growing conditions for crop trees. Economically, thinning should increase the financial return to the forest owner.

BIOLOGICAL FACTORS

Both hemlock and spruce respond well to release, particularly after stocking control and early commercial thinning. Thinning a stand removes part of the growing stock and results in reduced growth per acre immediately afterward because the remaining trees are not able to fully utilize the site. The reduction in growth is roughly proportional to the reduction in growing stock. Released trees build up root systems and crowns and are soon better able to exploit the resources of the site. Initial response probably comes from the availability of nutrients no longer being utilized by trees that were removed. Root systems may expand more rapidly than crowns because roots do not have to support themselves structurally (Smith 1962). Trees with large crowns will expand their photosynthetic area more rapidly than those with small crowns. There is evidence (Moller et al. 1954, Braathe 1957, Bradley 1963) that a stand not only recovers its normal rate of growth but also tends to make up the production lost when growth was below normal immediately after thinning. With heavy thinnings and long recovery periods, however, nutrients may be taken up by competing vegetation or leached from the site. In general, there is good recovery in wood production following heavy thinnings in the early part of the rotation. Heavy thinnings near the end of the rotation tend to reduce volume production.

The upper canopy not only intercepts a significant portion of total radiation but selectively filters out the most photosynthetically active wavelengths from the light that gets through (Assmann 1970). It follows that overtopped trees are not efficient producers of wood. They could be left, utilizing available light not used by the overstory. This would increase total wood productivity unless the moisture and nutrients required for growth were used by trees in the overstory.

An immediate effect of thinning is an increase in risk of wind damage. This risk is greatest after heavy thinning in stands nearing rotation age. Trees are tall, root systems may be poorly developed, and mutual support is an important factor in stand stability. As a

rule of thumb, removal of over one-third of stand basal area is not recommended. Thinning of young stands is less risky. Trees are short, respond quickly to release, eventually developing better roots and greater windfirmness than before thinning.

If dwarf mistletoe is present in a hemlock stand, thinning may stimulate growth of the parasite by increasing available light. Growth rate of host trees may be reduced even though trees are not killed. The problem is discussed in more detail later.

For any thinning operation, particularly when thinnings are removed from the site, care must be taken to protect the residual stand. Roots of hemlock and spruce are shallow and bark is thin. Hemlock is especially susceptible to decay because it is not protected by resin production to the same extent that Sitka spruce and Douglas-fir are. Damage to roots and stems provides entry courts for disease organisms (Wright and Isaac 1956, Worthington 1961, Hunt and Krueger 1962, Wallis and Morrison 1975).

Fomes annosus root rot may be a serious problem in thinned stands of hemlock. Infection of crop trees can occur from root contact with infected stumps left from the previous stand, from logging wounds on crop trees, or from root contact with stumps infected after thinning[7/] (Driver and Wood 1968, Wallis and Reynolds 1970). The number of stumps infected may be greatest soon after thinning, declining over a 5-year period (Morrison and Johnson 1978. Treatment of stumps immediately after cutting can help to prevent infection (Edmonds et al. 1969, Weir 1969, Russell et al. 1973). Borax has been used for this purpose in the past, but zinc chloride appears to have advantages in wet weather (Morrison 1977, Morrison and Johnson 1975).

EFFECTS OF THINNING ON TREES AND STANDS

Thinning determines the size distribution of the trees; for example, thinning from below eliminates smaller trees and immediately increases the average diameter and height of a stand. Thinning distributes the growth potential to fewer and larger stems. It tends to reduce log quality because branches, particularly in the lower crown, persist longer, grow larger, and produce larger knots. The added sunlight encourages epicormic branching in Sitka spruce.

Optimum thinning intensity usually is the maximum volume that can be removed from the stand without seriously reducing volume production. With heavier thinning, spacing may be so wide that the site is not fully utilized for timber production. Wide annual rings and large knots will lower wood quality. With lighter thinning, spacing may be so close that trees are suppressed. Rings will be narrow and knots small, but logs will be too small for efficient handling. The canopy should be deep enough for efficient use of light; but if tree crowns are too long, little clear wood is produced. Forty percent live crown is considered optimum for western hemlock (Walkup 1975). A common rule-of-thumb is to remove no more than 30 percent of the basal area at the time of the first commercial thinning.

[7/] Edmonds, R. L. 1968. Natural occurrence and control of *Fomes annosus* in precommercially thinned stands of western hemlock. M.S. thesis. Univ. Wash. 144 p.

Thinning affects species composition. Thinning from below removes mostly hemlock and thereby tends to increase the percentage of spruce crop trees. On drier sites where the whitepine weevil is a problem, thinning tends to favor hemlock by removing damaged spruce. Where Douglas-fir is present, thinning from below generally favors fir over both hemlock and spruce.

THINNING AS A STIMULANT TO UNDERSTORY VEGETATION

Thinning may stimulate establishment and growth of understory vegetation by increasing the amount of sunlight reaching the forest floor. This is beneficial if understory plants are desired for wildlife. It is detrimental if understory plants seriously compete with the timber stand for moisture and nutrients or, at a later date, with conifer regeneration. On the other hand, understory vegetation may help retain nutrients that otherwise might be leached out of the ecosystem. Thinning may speed decomposition by adding a mixture of broadleaf litter to the conifer litter from the timber stand (Smith 1962).

Thinning may also stimulate establishment of conifers, primarily hemlock, in the understory (Farr and Harris 1971). If thinning is done near rotation age, this could speed establishment of the next crop, as with the shelterwood system. Early thinning may result in a two-storied stand which will require attention during subsequent thinnings. The response of understory vegetation to various thinning regimes is now under study in Alaska.

ECONOMIC FACTORS

Financial evaluation of thinning requires careful formulation of management objectives. Common objectives are to increase stand yield--thereby, in many situations, justifying an increase in the present allowable cut; maximize profits with a limited capital investment; or perhaps improve the stand for wildlife or recreation use. Merits of several criteria for economic evaluation of management practices are discussed by Haley (1969) and Webster (1965).

The end products of the final crop need to be identified. Usually they are pulp logs, saw logs, or a combination. At present there may be little demand for thinnings, particularly where old growth is available and the added costs of thinning are not offset by lower stumpage costs; for example, in Alaska, British Columbia, and portions of Washington. Elsewhere, integrated utilization plants accept most log sizes and grades. Whatever the end products, their values, along with operating costs, can be estimated and discounted back to the present, with and without thinning. Doing this on an individual stand basis is often inadequate, because treatment of one stand will affect the management of other stands, and what is best for the timberlands division of a company may not be best for the company as a whole (Schweitzer 1972). An exception to this dollars-and-cents approach is on public land where timber production may not be the dominant use.

Thinnings can increase the financial return from the forest in several ways. Foremost is by utilization of trees that in an unthinned

stand would die and decay before the end of the rotation. In Douglas-fir, for example, Worthington and Staebler (1961) show mortality losses up to 33 percent, depending on age at first thinning, site class, utilization standard, and method of measuring volume. Mortality losses also are high in hemlock-spruce. Much of this loss can be anticipated and prevented by recognizing trees likely to drop out of the stand and removing them in periodic thinnings.

Commercial thinning provides an early return on the capital invested in growing stock, thereby freeing funds for other activities. The slow-growing trees usually are removed, leaving a more vigorous stand that provides a better rate of return on the investment.

Thinning affects rotation length by concentrating growth on fewer trees. The time to reach a given diameter is shortened. Transfer of growth to fewer trees occurs more rapidly in fast-growing young stands than in slower growing stands approaching rotation age. Some of the most effective thinnings are those made before the trees can be utilized and thus require an investment by the landowner.

Later thinnings necessarily must take some of the better trees. Near rotation age, when trees are larger, removal of a single tree leaves so large an opening in the canopy that it takes considerable time for adjacent trees to fill it and again fully utilize available sunlight.

Type of thinning affects capital investment in growing stock. For any given thinning intensity, removing more valuable trees in a crown thinning is more effective in reducing the capital invested than harvesting small trees in a low thinning. On the other hand, slow-growing intermediate and suppressed trees have a low percentage of growth. Their removal provides economic return with little loss in stand growth. Both respond to release. Some may need only a little diameter growth to become recruits into a merchantable size class, their entire volume being added to the stand at that time. Thinning from above can be risky, however, as intermediate and suppressed trees are generally not windfirm, and removal of larger, faster growing trees carries the risk of retaining genetically inferior trees.

Tree size is an important factor in the cost of thinning. In a young stand it takes longer and costs more per unit volume to fell small trees than large ones. As stands grow older and trees larger, cost differences because of size disappear, and felling cost is directly proportional to tree volume (Crowther 1964). Yarding and loading also cost more for small logs. These factors favor wide initial spacings, but this must be balanced against heavier branching that would result and the loss of increment from delayed closing of the canopy.

Volume per acre also affects thinning cost. The higher the volume harvested in one operation, the less time it takes to gather together a load of logs and the lower the cost of supervision.

Economically, thinnings should increase the financial return from a forest. Remote and low-site land may not justify thinning at all, or perhaps a single stocking control treatment early in the life of the stand will be all that is appropriate. The situation may be reversed, however, when thinning on poor sites is needed to bring trees into merchantable size classes.

THINNING STRATEGY

Thinnings should be governed by some reasonably definite schedule, indicating the desired density of the stand at all stages of its development. This is necessary not only for thinning control but also for predicting yields that will be obtained (Smith 1962). Thinning schedules are not fully developed for hemlock-spruce; but research, general theory, and field experience provide some guidelines.

The British approach has been to identify the productivity of the site in terms of maximum mean annual increment (Bradley et al. 1966, Hoyer 1967, Hamilton and Christie 1971). The height and age relationship is used to indicate this, much as we refer to height-over-age curves to determine site index. The British adopted a common objective for all species, thinning to an intensity that provides the greatest mean diameter increment for the main crop, consistent with maximum production of volume. This removes volume to the point that would affect total productivity. It was concluded that removing 70 percent of the maximum mean annual increment would meet this objective. The thinning cycle may be one to several years, but not so often that crop trees cannot respond enough to make full use of the growing space. The volume to remove in a particular thinning is obtained by multiplying 70 percent of the maximum mean annual increment by the thinning cycle (Bradley et al. 1966).

This method of controlling the volume of thinnings removed rather than controlling remaining growing stock has three advantages:

1. It provides consistent production from thinnings, which facilitates planning and makes for efficient harvesting.

2. It reduces the effect of an error in determining productivity class, since thinning volume is much less than growing stock volume.

3. It avoids a drastic reduction in growing stock if the stand is overstocked, which might lead to wind damage (Bradley 1971).

The lightest thinning to avoid volume loss would remove merchantable trees just before they drop out of the stand or salvage them before they decay. Light thinning causes growth to be distributed among more but smaller trees than with heavy thinning. Crowns and limbs will be smaller, thus improving wood quality.

There is little danger of thinning hemlock-spruce so lightly that stagnation occurs. Even in strictly even-aged stands there is usually adequate differentiation into crown classes. This is especially true with mixed hemlock-spruce stands because spruce usually assumes a dominant position in the canopy.

Competition begins early in hemlock-spruce stands, often when seedlings are less than a foot tall. Thinning at this stage is impractical with present techniques; and when seedlings are subjected to a short period of intense competition, weaklings drop out early in the rotation. Subsequent thinnings allow a choice from among the best trees of what was a considerably larger population, so there is little risk of depleting the gene pool.

Biologically, stocking should be controlled just before crowns of potential crop trees become constricted enough to materially slow diameter growth. But there are some practical considerations. It is difficult to move about in dense young stands, especially when there is a major component of Sitka spruce with its stiffer branches and sharp needles. This argues for delaying stocking control until low limbs die and begin to fall off. Also, hemlock-spruce stands often have small seedlings in the understory, seedlings too small to cut with a powersaw. If released, they respond vigorously and a two-storied stand results. It is common practice, therefore, to delay stocking control until tree crowns have been closed long enough to shade out most of these seedlings and associated understory plants. On the other hand, delaying the first thinning too long delays the release of crop trees and may leave stems of the crop trees exposed to sunscald or may contribute to snowbreakage or wind damage. Heavy thinnings are more risky than light ones. Exposing intermediate and suppressed trees is more risky than exposing trees in the upper canopy which have had more opportunity to build up windfirmness.

STOCKING CONTROL

Stocking control usually is prescribed in terms of tree spacing or stems per acre (fig. 35). All but the selected trees are cut or killed and left standing. Uniform spacing is usually compromised to leave the largest and most vigorous trees. Uniform spacing also may be sacrificed to improve species composition. Sometimes a tree will get so far ahead of its neighbors it is destined to have large limbs, poor log quality, and take up too much space. Such trees may also be removed in stocking control.

Figure 35.--This dense, 19-year-old hemlock-spruce stand at Maybeso Valley, Alaska, was thinned, leaving crop trees spaced 16 by 16 ft (4.9 by 4.9 m). About 6,300 trees per acre (15,600 per ha), aver-

Usually stocking control is done only once. The spacing is selected so that by the time tree crowns again are crowded, stems will be large enough for commercial thinning. The spacing to use, therefore, depends on future utilization standards and accessibility. If the stand is close to market, close spacing may be appropriate; if far from market, wider spacing should be used. Wide spacing is appropriate if the stand will be allowed to grow to rotation age without further thinning. This would require spacing so wide that the stand would not fully occupy the site for several years. It would encourage brush establishment in the understory. Additional conifer regeneration would likely become established, perhaps defeating the purpose of the thinning. Common spacings at present are 9 by 9 to 12 by 12 feet or 538 to 302 trees per acre (2.7 by 2.7 to 3.7 by 3.7m or 1,329 to 746 trees per ha) in anticipation of at least one commercial thinning later in the rotation.

Average stand density increases with latitude (Meyer 1937, Barnes 1962). Stands in Alaska have more stems per acre but lower average diameter and less volume than in the Pacific Northwest. The reason probably is that site productivity decreases with latitude (Farr and Harris 1979). Also, seedling survival may be greater in the cool, wet northern climate (Harris and Farr 1974).

Timing of the first thinning depends on many practical considerations, not the least of which is the landowner's policy on silvicultural investments and the owner's ability to finance a thinning, the benefits of which will not accrue for several years. Most owners of large areas of industrial forest land and the public agencies in Oregon, Washington, and British Columbia have aggressive stocking control programs in hemlock-spruce stands. For the most part, owners of small areas are managing their land less intensively.

COMMERCIAL THINNING

The first commercial thinning may be conducted as soon as the trees are crowded enough to need thinning and the operation will at least break even economically. This may be early in the rotation if stocking control has concentrated growth on fewer stems, later if it is the first thinning. Timing also depends on the accessibility to market and the market for small logs. Subsequent thinnings can be made as tree crowns expand and fill in the gaps in the canopy. High sites should be thinned more often than low sites and young stands more often than old stands.

LOW THINNING

Low thinning forestalls natural mortality that occurs as trees become overtopped and crowded out of the stand. Removal of suppressed trees relieves competition for moisture and nutrients but does little to relieve competition for sunlight. Because openings in the main canopy are avoided, low thinnings retain the mutual protection trees provide each other against storm damage. On the other hand, upper canopy trees are not stimulated to build up added windfirmness. Should a break occur in the canopy, continuing wind damage may follow.

Thinning from below tends toward an orchardlike condition in the ain canopy, in which sunlight penetrating the canopy is not used for ood production because there are no tree crowns below to utilize it. articularly with very tolerant trees like hemlock, it seems advisable o maintain a deep forest canopy for full utilization of sunlight.

Low thinning requires a minimum of marking skill because it emoves trees whose crowns have dropped below the main canopy. Crown hinning is more flexible and requires more marking skill.

ROWN THINNING

Crown thinning removes codominant and dominant trees from the ain canopy to favor more promising trees in these same crown classes. ominants may be favored as the most vigorous and windfirm crop trees ut sometimes are removed because of large limbs that degrade log uality. Codominants usually have better quality but tend to be naller and less windfirm. In a strict crown thinning, no intermediate nd suppressed trees are harvested, and their presence tends to restrict evelopment of understory vegetation. Opening up the main canopy ermits better light penetration and slows mortality of lower branches. itka spruce may be stimulated to develop epicormic branches. Crown hinning may stimulate understory trees to grow into a merchantable iameter class. The added light may encourage growth of understory egetation, thereby improving forage for deer.

In the Scottish eclectic method of thinning used in some Sitka pruce plantations in Britain, the main crop trees are identified and he major thinning objective then becomes uninterrupted development of he effective crowns on these trees. A deep canopy is maintained by eaving smaller trees (the followers) surrounding each crop tree. ominant and strong codominant competitors of selected crop trees are emoved as needed, and trees suppressing or otherwise crowding desired ollowers are removed (MacDonald 1963).

ELECTION THINNING

Selection thinning of dominants in hemlock-spruce stands generally s limited to removal of large, poorly formed trees occupying space ut of proportion to the wood values produced. These are best removed arly in the life of the stand when trees are more wind resistant and hile nearby subordinate trees have adequate crowns to respond to elease. With tolerant species like hemlock, subordinate trees usually re present to fill spaces left by removal of rough dominants. Heavy r repeated thinning of dominants is not suitable for hemlock-spruce ecause of increased probability of wind damage to the residual stand.

OMBINATION THINNING

Most hemlock-spruce stands are variable enough that no single ype of thinning is sufficient. Often there are rough dominants ccupying excessive growing space which should be removed if other rees are available to replace them. Marking policy may favor hemlock, pruce, or perhaps an associated species, justifying departure from

the usual criteria of crown position and tree quality. Thinning to minimize wind damage often is an overriding criterion as will be discussed later.

A logical thinning sequence begins with a precommercial thinning--a combination of mechanical and other types of thinning--followed by one or more crown thinnings but taking trees from the lower canopy as they reach merchantable size. Thus, later thinnings are called low thinnings.

In general, type of thinning has little effect on gross volume production (Bradley 1963). Bradley concluded that for practical purposes thinning may be controlled in intensity, independent of type of thinning, and that changes from one type of thinning to another can be made during the life of a stand without seriously complicating calculation of total volume production.

TREE SELECTION AND HARVEST

Selecting the Individual Tree

The general approach to thinning is to identify the trees most efficient for volume production--those that produce the greatest volume of wood for the space they occupy--and thin to favor them. The success of thinning depends on the subsequent development of these individual trees.

Matthews (1963) generalized for several species, including the spruces, that efficient trees have relatively long, narrow crowns with upper branches angling upward and lower branches more or less horizontal. Trees with large crowns and branches are not necessarily the most efficient producers for the space occupied. Seed production makes considerable demands on carbohydrate resources of a tree at the expense of wood production. Heavy seed producers, unless needed to seed adjacent areas, are best thinned out of the stand. Trees to favor have straight stems without excessive taper; have small limbs; are circular in cross-section; and are free of buttressing, spiral grain, fluting, and forking. Efficient trees usually have a dense mass of healthy foliage. It is particularly important to recognize crop and noncrop trees early in the life of the stand, even though some of their characteristics are difficult to detect at that time.

If a policy is set to favor a particular species, then some compromises in tree quality may be necessary. The desired species may be present but not the best tree from the standpoint of position in the canopy and health.

There are several commonsense guidelines to timber marking which normally apply, whatever the general approach to thinning. Large-crowned dominants taking up excessive growing space should be marked if it appears that their increment will be replaced by release of nearby trees. Mistletoe-infected trees, rotten trees, and poorly formed trees should be cut. All merchantable dead and down material should be designated for removal. Hangups, trees that lodge into others when cut, are a common problem in dense hemlock-spruce stands. The timber marker can help to alleviate this problem by not marking a tree that

ay hang up or by marking it and the tree it would lodge against. cattered trees far from the landing are costly to harvest. The arker should be familiar with yarding procedures and costs and consider hese factors in selecting trees for harvest.

Whatever the intensity and type of thinning prescribed for an rea, the timber marker should be allowed discretion in handling pecial situations. He may encounter wide variations in soil moisture, pecies composition, stocking, competing vegetation, topography, and ge class. Areas subject to storm damage require special treatment. o do areas with more than one age class of trees. Thinning rules may e varied to meet market demands for special products or log sizes. he timber marker should be provided with adequate guidelines and have he training, experience, and authority to handle such situations as hey arise in the field.

Equipment and Techniques Used for Stocking Control or Thinning

Both powersaws and chemicals have been used for control of stocking. aws are the less costly method when there are many small stems to ut, chemicals when there are fewer and larger stems. Schroedel (1971) nalyzed costs in western Washington and recommended using powersaws where ne average stand diameter is less than 2.5 inches (6 cm) and 2,000 or ore stems per acre will be cut. Powersaws also are an advantage over nemicals when the trees to be cut have limbs all the way to the round. MSMA (monosodium acid methanearsonate) and cacodylic acid have een the chemicals commonly used. These organic arsenicals can be angerous to the applicator unless adequate precautions are taken Wagner and Weswig 1974). Some organizations are minimizing chemical se because of the problem of monitoring health of employees. Also, ecause it is difficult for thinners to distinguish treated trees, ninning standards are difficult to maintain and the crew's job satis- action suffers (Waterman 1976). Standing dead trees deteriorate more lowly than slash on the ground, and this is also a point against oisoning or girdling. Public concern over use of herbicides is nother. For these reasons cutting trees rather than poisoning or irdling them is the preferred method of removing unmerchantable trees oday.

With powersaws, the usual technique is to sever the stems and ove on. Some trees will fall, but many will be held up by adjacent rees and will be felled later by wind or snow. Initially, thinning eaves an unsightly tangle of dead limbs and stems. This residue can e cleaned up by lopping, piling, burning, or chipping; but this is ostly. Cleanup usually is limited to keeping slash off roads and out f streams and roadside ditches. An alternative is to leave unthinned trips along roads and streams. In sensitive areas these strips can be hinned after the residue on the main area has fallen to the ground. hen only a limited amount of residue needs to be treated.

Yarding of Thinnings

Hemlock and spruce trees are easily damaged because of their thin ark and shallow roots, particularly during active growing periods. pecial care should be taken to protect them from logging injury.

This is difficult because trees are growing during the summer, often the only time crawler tractors or rubber-tired skidders can operate. During other seasons, these machines may cause soil compaction and root damage or may simply get bogged down in the mud.

The construction of permanent tractor trails and landings in advance of thinning operations can do much to alleviate damage to the stand, protect soil and water resources, and improve safety and harvesting efficiency. Long-term as well as short-term requirements for thinning operations can be met by careful preplanning and construction. The technique is currently being tested in Oregon[7/]

Cable yarding often is preferable to use of tracked or wheeled vehicles and is the only practical means on steep slopes. It avoids most root injury and soil compaction. Stem injury, however, may be greater. Special care should be taken in logging layout, choker setting, and yarding. Improved techniques need to be developed.

A study in the nearby Douglas-fir type (Aulerich et al. 1974) showed that log production rates for skyline yarding were greater than for tractors on steep ground, but less on gentle ground. Overall, skyline yarding cost 1.5 to 1.6 times more than tractor yarding. It left more slash but caused less soil compaction and resulted in fewer serious wounds to residual trees.

PRESENT STATUS OF THINNING

Research and experience in thinning hemlock-spruce are recent, and few long-term results are available. In Oregon and Washington thinning began after World War II in stands 100 to 125 years old. These stands were past rotation age, but there were large acreages in these and older age classes. To meet even-flow objectives harvest cutting time was extended through commercial thinnings. Objectives were to salvage existing mortality, remove defective trees, and remove trees expected to die before the stand was scheduled for final harvest cutting. Thinnings were confined to gentle topography where crawler tractors could be used. As demand for timber increased and technology for handling small logs improved, commercial thinning spread to more ownerships, younger stands, and, with development of cable methods, to steeper slopes. The first commercial thinning in coastal hemlock stands under age 50 years was started in 1947, when a 47-year-old stand of hemlock was thinned (see footnote 7).

Commercial thinning is becoming more common in Oregon and Washington and spreading northward. Conventional logging methods have not proved satisfactory and economics has been a limiting factor in thinning hemlock (Dick 1976). But there has not been time for long-term tests of thinning, and thinning guides are only in the development stages. Managed-stand yield tables have been prepared for pure Sitka spruce and pure western hemlock plantations in Great Britain (Hamilton and Christie 1971, Bradley et al. 1966), but comparable information for managed stands of hemlock-spruce has not been developed for North America.

[7/] Personal communication from Donald B. Malmberg, Crown Zellerbach Corp., Seaside, Oregon, 1977.

In Alaska, thinning has been limited because of the predominance old-growth stands, poor accessibility, and limited markets for ll material. A test in an even-age stand near rotation age showed t thinning favored growth of crop trees and resulted in prolific eneration (Godman 1951, Farr and Harris 1971).

Stocking control in precommercial stands of hemlock-spruce is now mon practice in Oregon and Washington. In British Columbia a enile spacing program began in 1961. By 1977, 105,735 acres 823 ha) had been spaced, mostly on the Vancouver Forest District. t of this has been done on licensed tree farms and certified tree ms (Johnson 1977). In Alaska stocking control is being done on a ll scale, along with studies designed to develop managed stand ld tables.

Although detailed silvicultural effects and financial returns not be predicted at this time, adoption of intensive thinning grams by forest industry and government agencies illustrates the espread conviction on the part of forest managers that thinning lock-spruce will indeed pay.

FOREST FERTILIZATION

In the Pacific Northwest, interest in forest fertilization began ut 1950 when fertilizer trials were begun in immature Douglas-fir nds in western Washington (Gessel et al. 1969). Results were ouraging and by the mid-1960's private timber companies had aerially lied nitrogen in the form of urea over several thousand acres ark 1967, Forbes 1966).

Most fertilization in the Pacific Northwest has been of Douglas-fir, interest has also been shown in western hemlock. By 1975, fertilizer als had been established on nearly 1,000 hemlock plots (DeBell 1975, ell et al. 1975, Webster et al. 1976). The nutrient requirement of lock has not been extensively studied (van den Driessche 1976).

In the case of Sitka spruce, little experience has been gained on Pacific coast although a great deal of work has been done in Great tain. Extensive studies on the nutrition of Sitka spruce, mainly nurseries, date back to the 1950's (Benzian 1965). By the mid-1960's y young stands of Sitka spruce had been aerially fertilized in tland (Davies 1967, 1969).

In Alaska, the U.S. Forest Service tested large-scale aerial lications of urea in young stands of hemlock-spruce to gain experience methods, costs, and logistics of large-scale applications in remote as (Johnson 1970, Bowkett 1969). Between 1969 and 1972, about 00 acres (2,200 ha) of 6- to 15-year-old hemlock-spruce stands were tilized by helicopter using urea prills at a rate of 400 lb per e (448 kg/ha) (Farr et al. 1977).

Growth response of western hemlock from fertilizer application in hemlock-spruce type has been inconsistent. Response of western lock in basal area growth on nearly 1,000 plots in Oregon, Washington, British Columbia fertilized primarily with urea ranged from -20 to

+47 percent (DeBell 1975). A detailed analysis by Webster et al. (1976) showed that response differed by geographic location; response in coastal areas within the hemlock-spruce type was generally slight (often negative), whereas inland stands responded better. There also appeared to be a tendency for an increase in response with latitude from southern Oregon to northern Vancouver Island. Trees in the upper crown classes showed better response than trees in lower crown classes. No consistent trends emerged regarding response associated with stand age, stand density, site quality, or soil type. Response in thinned stands was generally higher and more consistent than in unthinned stands.

Growth response of Sitka spruce in mixed stands of hemlock-spruce was greater and more consistent than hemlock, based on tests near Seaside, Oregon (Webster et al. 1976). In comparing tree growth associated with fertilization, Farr et al. (1977) found that 2 years after application of urea the growth rate of Sitka spruce was from 20 to 30 percent greater in height and diameter on areas fertilized than on areas not fertilized; by the 5th or 6th year, there was little difference in growth rate. Response of western hemlock could not be measured because hemlock on both fertilized and unfertilized areas were infected by the fungus *Sirococcus strobilinus* (Farr et al. 1977). Later investigations by Wicker et al. (1978) indicated some tendency for fertilizer application to favor the fungus, but results were not conclusive.

The effect of forest fertilization on water quality was also examined in Alaska. Meehan et al. (1975) studied water quality of two streams whose watersheds had received aerial applications of urea. He found that concentrations of nitrate nitrogen in both streams were higher than normal during a 1-year sampling period. An initial short-term increase in ammonia-nitrogen occurred in one stream, apparently from the inadvertent direct application of fertilizer to the stream. In all cases, however, concentration of nitrogen remained well below the upper limits permitted for human consumption.

Fertilization has been proposed as a substitute for precommercial thinning. The rationale for this has been that adding nutrients increases site productivity and tree growth, which in turn hastens natural thinning. Field trials have failed to clearly demonstrate the effectiveness of this approach. Studies indicate that reductions in overstocking as a result of fertilization will be much slower and in most cases less beneficial than from thinning (Miller 1976).

Aerial fertilization is an attractive tool for forest management because large areas may be treated quickly with a minimum of effort. Growth responses on the average, however, have been low, inconsistent, and of relatively short duration. At present, fertilization alone does not appear promising. We still know far too little about the basic nutritional requirements of hemlock and spruce and their responses to fertilizer to be able to predict results. Application of fertilizer alone does not now appear to be sound practice in the hemlock-spruce type.

GROWTH AND YIELD

Western hemlock-Sitka spruce is one of the world's most productive forest types. The high productivity is attributed to the mild, moist

climate during the growing season and to high genetic capability of the species (fig. 36). Pacific Northwest tree species survived Pleistocene glaciation without serious depletion of the gene pool,

Figure 36.--A mixed stand of western hemlock and Sitka spruce 79 years old. Cascade Head Experimental Forest, Oregon.

because the north-south orientation of the mountain ranges permitted species to migrate south and north as the climate varied and glaciers advanced and receded. In contrast, species in many other parts of the world were cut off by east-west mountain ranges (Silen 1976).

The Pacific Northwest coastal climate is excellent for tree growth. Temperatures are mild during the long growing season and even on clear days do not get high enough to excessively increase respiration rates. Soil moisture is adequate. So, apparently, is solar radiation, in spite of the cloudy weather.

The Olympic area appears optimum for hemlock-spruce. Dimock (1958b) measured growth on three groups of 0.2-acre (0.08-ha) plots in 35- to 60-year-old stands on the Olympic Peninsula, Washington. Hundred-year site index was 160 to 200 feet (49 to 61 m); net periodic annual increment for a 5-year measurement period ranged from 160 to 293 ft^3 per acre (11.2 to 20.5 m^3/ha). Northward, productivity decreases with increasing latitude and decreasing temperature. Through most of the type, 100-year site index decreases about 3.4 ft (1.0 m) per degree of latitude and averages about 156 ft (48 m) in Lincoln County, Oregon, and 108 ft (33 m) in northern southeast Alaska (Farr and Harris 1979).

A 26-year-old western hemlock stand in coastal Oregon believed to be at a peak stage of production had a total biomass of 103 tons per acre (231 metric tons/ha); 65 percent was in the main stem (table 5). This is a huge biomass accumulation in only 26 years, and net accumulation was continuing at a rate of 16.1 tons per acre (36.1 metric tons/ha) per year (Fujimori 1971).

Table 5--Accumulated and annual biomass production of a 26-year-old western hemlock stand on the Oregon coast, dry weight basis

Component	Accumulated biomass		Current net annual production	
	Tons per acre	Metric tons per hectare[1/]	Tons per acre	Metric tons per hectare[1/]
Stem	67.3	150.9	9.1	20.4
Branch	9.2	20.7	1.9	4.3
Leaf	9.4	21.1	2.7	6.0
Root	17.1	38.4	2.4	5.5
Whole	103.0	231.1	16.1	36.2

[1/] From Fujimori (1971).

EARLY HEIGHT GROWTH

Juvenile height growth of hemlock and spruce seedlings varies with site index, the genetic potential of each seedling, and the microenvironment where the seedling happens to germinate or be planted. Microenvironments vary widely, and their influence often dwarfs other factors for the first few years. A seedling with very rapid growth potential may do poorly the first few years because of competing vegetation or other localized environmental conditions, and juvenile height growth may lead to an underestimation of subsequent growth. In other situations the converse may be true.

Estimates of stand age are often made by aging trees at breast height, 4.5 ft (1.4 m) above the root collar, and estimating the number of years for the seedling to have reached that height. Age at breast height rather than total age is often preferred as a more useful variable for subsequent growth and yield estimates.

The juvenile growth period is an important part of the rotation, and any condition that slows growth will increase rotation length or reduce yield. For maximum growth, competing vegetation should be controlled and overcrowding of seedlings avoided or spacing treatments applied. Treatment must be applied early in the life of a stand to be most effective. If delayed too long, much of the opportunity for improving stand growth and yield will be lost.

SEASONAL DISTRIBUTION OF LEADER GROWTH

Seasonal leader growth of both hemlock and spruce starts in late April or early May, accelerates slowly for 2 to 3 weeks, undergoes a sustained period of rapid elongation, and finally tapers off for several weeks in July and August. Godman and Gregory (1955) took

ekly measurements of leader growth at Hollis near Ketchikan, Alaska, d found that both species began growth about the same time but that ruce grew faster and stopped growth 2 to 6 weeks sooner than hemlock ig. 37). Gregory (1957a) compared seasonal distribution of hemlock ader growth at Hollis, Alaska, with growth at Cowichan Lake on ncouver Island (Buckland 1956) and found time of growth initiation d shape of the growth curves similar.

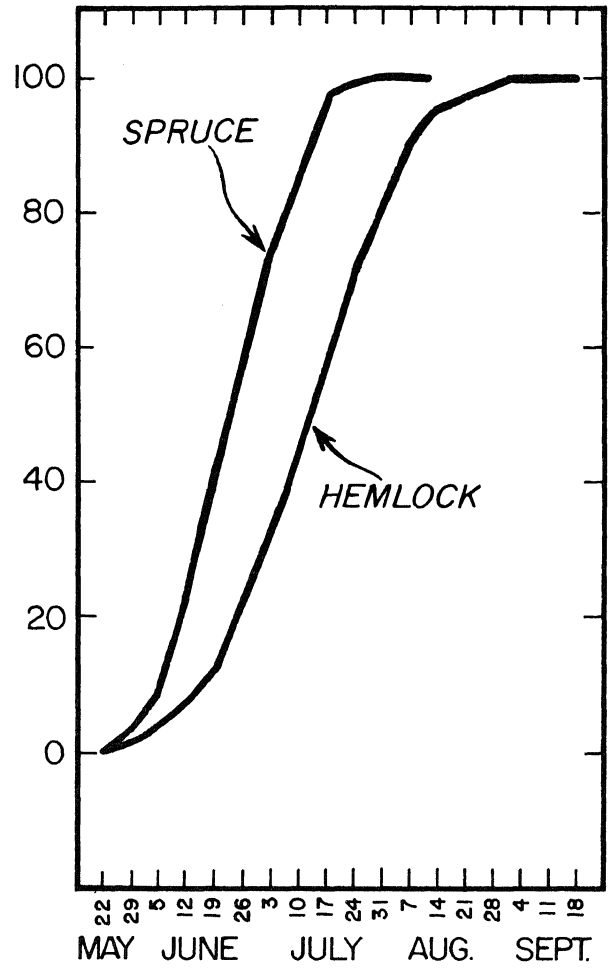

Figure 37.--Cumulative leader growth of spruce and hemlock, Hollis, Alaska, 1952 (adapted from Godman and Gregory 1955).

CROWN CLOSURE

As soon as crowns of dominant and codominant saplings form a losed canopy, they begin to shade out understory vegetation. After a ew years, the forest floor becomes almost devoid of shrubs and herbs ig. 38). Even tolerant hemlocks begin to die out, as part of the ng trend from thousands to only a hundred or so trees per acre.

Age of crown closure varies with density of stocking. Osborn 1968) measured the following percent closure of 9-year-old western

hemlock planted at different spacings near Haney, B.C.:

Spacing (feet)	Crown closure (percent)
3 by 3	58
6 by 6	41
9 by 9	29
12 by 12	19

Figure 38.--Forty years after clearcutting, the forest floor beneath this dense second-growth hemlock-spruce stand is almost devoid of shrubs and herbs. Virgin Bay, Alaska.

GROWTH AND YIELD ESTIMATES

Old-Growth Stands

Future yield for sites supporting old-growth, uneven-aged stands cannot be predicted from direct measurements of site based on height and age of trees in the stand (Taylor 1933). Many dominant and codominant trees have been suppressed at one time. Age is difficult to determine accurately. Trees over 300 years old virtually cease height growth, so that height-age curves are inaccurate. Estimates of site productivity in old-growth stands can best be obtained from examination of the soil. Preliminary soil-site relationships have been developed for southeast Alaska, based primarily on depth and drainage of soil and on parent material[8/] (Stephens et al. 1969).

8/ F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Paulson. June 1969. Soils and associated ecosystems of the Tongass. USDA For. Serv. Alaska Reg., draft

Taylor (1933) noted a reduction in site productivity with the increasing buildup of raw humus as stands approached climax. This buildup is reversed when the site is exposed to full sunlight after logging or destruction of the timber stand by wind or other catastrophe. Soil temperature increases, hastening decomposition of humus and lowering acidity of the soil. Growth of understory vegetation provides broad-leaved litter, generally beneficial to the soil. In short, the site is improved and, particularly, is more favorable for spruce.

High productivity of young-growth hemlock-spruce stands is a strong argument for harvesting old growth and establishing new stands. Average volume of old-growth climax stands in southeast Alaska is about 5,900 ft^3/acre (400 m^3/ha). Annual growth is offset by mortality so that net stand growth is zero (Hutchison and LaBau 1975). In contrast, young-growth stands on a 100-year rotation on an average site will produce about double the cubic-foot volume maintained in most old-growth stands (Taylor 1949). Annual net growth of all young-growth stands in southeast Alaska is 1.53 percent of their total volume (Hutchison and LaBau 1975).

Unthinned Even-Aged Stands

Yield tables for unthinned stands have been prepared for mixed hemlock-spruce and for pure stands of each species. The first tables were for hemlock in British Columbia (Province of British Columbia 1926). When Taylor (1934) published yield tables for young-growth hemlock-spruce stands in southeast Alaska. These still are in use and are the basis for predicting productivity of the young growth that follows harvesting of southeast Alaska's overmature stands. For predicting productivity, Taylor used anamorphic techniques to develop proportional site index curves. His yield tables are for normally stocked stands. They are entered by site index and age, and, if the stand to be evaluated is less than normally stocked, tabulated values are adjusted downward. This may be done by comparing the basal area of the stand with that of a well-stocked stand as given in the tables. For example, if the stand has a basal area per acre 90 percent of normal, then tabular volumes should be reduced 10 percent.

In 1937 Meyer published yield tables for hemlock-spruce for the North Pacific coast. He used 300 of Taylor's plots from Alaska, 94 plots from British Columbia, and measured 294 new plots in Oregon and Washington. Meyer developed proportional site index curves that did not differ appreciably from those prepared by Taylor. He recognized that a high percentage of spruce in a stand increased the yield and so he provided tables to correct for variations in species composition. He judged the effect on site index to be minor and did not make an adjustment for this. He noted differences between the Oregon-Washington and Alaska data but balanced them to produce a single set of yield tables.

Almost concurrently, supplementary tables were published providing additional information for trees 6.6 in (17 cm) and more in diameter at breast height (Pacific Northwest Forest and Range Experiment Station 1937).

Subsequent use and evaluation of Meyer's tables indicated accuracy could be improved by preparing separate tables for each species and geographic location.[9/] Barnes (1962) did this for stands in which hemlock comprised at least 40 percent of the basal area; he used the same basic data as Meyers but discarded plots with over 60 percent spruce. He found that stands in Oregon and Washington of the same site and age had about 20 percent greater average diameters than stands in British Columbia and Alaska and even greater differences in volume. Apparently young stands in northern areas are more dense at early ages, with earlier crown closure and more severe competition than stands in the south. Average heights of stands of the same age and site index were about 15 percent taller in Oregon and Washington than in British Columbia and Alaska. Because of these differences, Barnes prepared separate hemlock yield tables for each of the three areas. He also developed and presented in the same report a yield table using average stand diameter as the independent variable rather than site index and age.

Recently, Chambers and Wilson (1972) developed empirical yield tables for hemlock stands in western Washington. They are based on 232 sample plots in stands where the volume averaged 85-percent hemlock. Site indices ranged from 87 to 232, based on Barnes' (1962) site index curves. The tables are entered with site index and age. Tables are included for stands with less-than-normal basal area to facilitate yield predictions for stands not fully stocked. Also included are yield tables based on average stand diameter and basal area.

All these natural-stand yield tables give only net growth and are not appropriate for intensive management where net growth plus thinnings approaches gross growth (Curtis 1972). Their usefulness will diminish with time. Most prolonged use will be in Alaska where thinning is more expensive because accessibility to stands is limited and labor costs are high. Some stocking control treatment early in the rotation is now being done, however, and more is expected as timber values increase. Early thinning would alleviate the problem of small stem diameters caused by dense stocking and could greatly increase usable yield.

Several organizations are developing stand simulation models for projection and evaluation of stand growth and development under different management regimes. Lin (1970) developed a method for assessing available growing space of young western hemlock and a computer model for simulating stand growth. Research with other species has shown that growth response can be integrated with various thinning cycles, harvest cutting techniques, and estimated costs and returns as a basis for selecting management alternatives and developing management plans (Myers 1969, 1973, 1974). Myers (1971) also developed field and computer techniques for preparation of managed-stand yield tables.

Site-index curves for hemlock-spruce (Taylor 1934, Meyer 1937) and for hemlock alone (Barnes 1962) are available. Site index is based on height at age 100.

Wiley (1976) reported development of site-index tables for western hemlock in western Washington, Oregon, and British Columbia. The

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[9/] Robinson, Walter Lee. 1951. Application of western hemlock yield tables for Oregon and Washington to stands in Alaska and British Columbia. M.S. thesis, Oreg. State Coll. [Univ.], Corvallis, 54 p., illus.

ables differ from those currently available in that site index age is owered from total age 100 years to breast-high age 50. Although ased on plots representing coastal and inland situations, glaciated d nonglaciated soils, and high and low stand densities, tests showed growth differences that would justify separate equations.

In Alaska, additional stem analyses of hemlock and spruce indicate at height growth differs from published site curves, the difference eing greater for low sites than for high sites. The general shape of e curves apparently differs by soil series, and accuracy of yield redictions might be improved by development of different curves for jor soil types (Harris and Farr 1974).

Even-Aged Thinned Stands

The only yield tables for managed stands presently available for mlock and spruce were developed by Bradley et al. (1966) for pure antations of each species in Great Britain. Original tables were in perial units, but the tables for western hemlock were converted to erican units of measure by Hoyer (1967); later, tables for both ecies were converted to metric units (Hamilton and Christie 1971). e tables are based on permanent plot records in Britain. They ould be used with caution in North America because of different vironmental conditions and management practices. They do, however, ovide a general guide until local experience is available.

Several organizations are working on stand simulation models, nging from whole-stand models to single-tree-distance-dependent dels. A cooperative effort is currently underway between private mpanies and government agencies to pool information for western mlock and develop managed-stand yield tables for this species in egon and Washington.

ECIES TO MANAGE

Important gains in economic return may be made by proper selection species. Most acres in the coastal fog belt will grow not only mlock and spruce in various proportions but also one or more asso- ated species. Each species responds differently to variations in il and other environmental factors, so for any given habitat there ould be a species or combination of species that will be more productive an all others. Also, there is genetic variation within a species, d one genotype will do well in a given habitat whereas another will t. There is considerable ecological justification for preferring ands of mixed species over stands of single species from the standpoint resistance to insects and disease. Not enough is known about the ecies or the habitats to say what mix should be grown on each acre, t there are some general guidelines.

In Oregon, Washington, and British Columbia forest managers often earcut hemlock-spruce, then plant Douglas-fir. Expecting hemlock d some spruce to seed in to provide a mixed stand, they usually plant e fir at a wide spacing. Douglas-fir is thus extended westward into e hemlock-spruce type and usually replaces spruce in the dominant nopy. One reason for this practice is that the white pine weevil

repeatedly damages spruce. Damage is more severe in the drier eastern part of the spruce range where hemlock-spruce merges into hemlock-fir. Another reason is that fir seed and seedlings have been more readily available for planting than either spruce or hemlock. A third reason is that Douglas-fir timber values have been higher than those of hemlock or spruce, and this also provided justification for extending fir westward. In recent years, however, hemlock and spruce values have increased relative to fir; and what they will be a rotation ahead cannot be accurately predicted.

The best course of action may be to establish the species or species combination that will produce the most wood fiber. In Oregon and Washington, usually this will be hemlock-spruce, hemlock-fir, or perhaps pure hemlock. Smith (1962) hypothesized that a pure stand of the subordinate species of a stratified mixture--in our example western hemlock--probably would be more productive than the mixture of which it could be a part. In areas along the ocean front affected by salt spray, the best species may be pure spruce. There are areas where one or more of the associated species will do well, such as red alder or western redcedar over a high water table or shore pine on maturing sand dunes.

In the transition zone between the hemlock-spruce and Douglas-fir forest types, hemlock-spruce generally is more productive than pure Douglas-fir. Meyer (1937) noted that 100-year site index 150 is common for hemlock-spruce in Oregon and Washington. Site index for Douglas-fir is slightly higher on the same areas, but Douglas-fir stands usually have fewer trees per acre. For cubic-foot volume in the 20- to 80-year age classes, he found hemlock-spruce productivity ranged from 22 to 41 percent more than Douglas-fir, depending on age and difference in site index (table 6). Other authors have calculated similar differences (Dimock 1958a, Hiley 1950). The superiority of hemlock-spruce, however, is questioned by Scott (1962) on the basis that hemlock's greater tolerance permits a larger proportion of total yield to remain alive than would be the case with Douglas-fir. Since most volume data are based on a single observation date, more of the Douglas-fir production could have been lost through mortality. When aboveground net primary biomass production was compared in stands of coastal hemlock-spruce and interior Douglas-fir, Grier (1976) found that production in a 26-year-old hemlock-spruce stand was 1.6 times that of Douglas-fir. Productivity of coastal hemlock-spruce appeared to decline more rapidly with age than did that of Douglas-fir. British yield tables show similar yields of hemlock, spruce, and fir (Hamilton and Christie 1971).

Table 6--Comparison of hemlock-spruce and Douglas-fir volume, by site index (100-year basis), Oregon and Washington[1/]

Age	Hemlock-spruce site index		Douglas-fir site index			
	150		150		160	
Years	ft^3/acre	m^3/ha	ft^3/acre	m^3/ha	ft^3/acre	m^3/ha
40	7,500	520	5,750	400	6,160	430
60	13,100	920	9,490	660	10,200	710
80	17,500	1 220	12,400	870	13,360	940

[1/] Based on Meyer (1937).

Steinbrenner (1976) compared the yields of natural stands of western hemlock and Douglas-fir growing on similar soil types in southwest Washington. For nearly all soils, the site index of hemlock was lower than for Douglas-fir. Potential yields, however, averaged 33 percent higher for western hemlock than for Douglas-fir (table 7). Wiley (1976) showed that not only can hemlock stands carry more trees per acre than Douglas-fir for a given average d.b.h. but also hemlock contains more volume than Douglas-fir of the same diameter and height.

Table 7 (reproduced from Steinbrenner 1976, with permission)--

Douglas-Fir and Western Hemlock/Coastal Soils
YIELDS OF NATURAL STANDS

Soil Series	Extent (M Acres)	Douglas-Fir Site Index (Feet)	Douglas-Fir MAI (Cu. Ft.)	Hemlock Site Index (Feet)	Hemlock MAI (Cu. Ft.)
Arctic	35	130	248	120	356
Astoria	80	140	285	110	318
Capps	20	120	222	110	318
Dahlia	25	130	248	110	318
Impie	45	130	248	120	356
Knappton	40	110	198	110	318
Lytell	42	140	285	110	318
Mopang	28	130	248	110	318
Price	44	130	248	120	356
Willapa	44	120	222	110	318
	403				
Weighted Average:		130	248	113	329

Total Yield (M Cunits)		
Douglas-Fir	999	
Hemlock	1,326	
Difference	327	(+33%)

Little is known about the productivity of the Douglas-fir and hemlock mixture. Because of hemlock's tolerance for shade and ability to utilize light filtering through the dominant canopy, one may hypothesize that the mixture is more productive than Douglas-fir alone. Also, the mixture of the two species with differing root systems may utilize soil nutrients and moisture better than fir could do alone. Replacement of Sitka spruce by Douglas-fir appears to be a reasonable management alternative toward the south on sites where Douglas-fir will do well, especially where the white pine weevil is a problem.

Westward from the transition zone and approaching the coastline, site index of Douglas-fir drops off relative to hemlock-spruce and thus increases the productivity differential favoring the coastal species. Here, it would be better to establish hemlock-spruce or, in areas where white pine weevil is a problem, hemlock alone.

Westward limits for Douglas-fir are related to soil type; site index is generally better on coarse-textured soils than on fine-textured soils. For example, near Sand Lake, Oregon, Douglas-fir grows well almost to the beach on sandy soils. On finer textured soils north and south of Sand Lake, it usually drops out of the stand well back from the beach.

On the east side of the transition zone, care should be taken to avoid planting Sitka spruce where its site index is low relative to hemlock-fir and where susceptibility to weevil damage is high.

In Alaska, Taylor (1929, 1934) found young-growth stands with a mixture of hemlock and spruce more productive than pure stands of either species. Dense hemlock thickets tend to grow slowly on poor sites. An undisturbed layer of raw humus favors establishment of hemlock. Spruce is favored by disturbing the humus layer or mixing it with mineral soil. A mixture of hemlock in the intermediate and suppressed crown classes utilizes light otherwise lost or utilized only by understory vegetation. The hemlock also shades out lower spruce branches and retards growth of epicormic branches.

Red alder initially grows more rapidly than hemlock-spruce and, on a very short rotation, would be a viable alternative as a species to manage. Berntsen (1961) compared alder and conifer stands on the Oregon coast and found that at age 20 alder stands had double the volume of Douglas-fir stands but that by age 30 the growth rate of fir surpassed that of alder and thereafter continued to forge ahead.

Zavitkovski and Stevens (1972) reported the maximum growth period for alder as age 10 to 15 years and recommended that best yields would result from harvesting before 20 years of age. DeBell (1972), Smith and DeBell (1973, 1974), and DeBell et al. (1978) pointed out some effects of stand density on yield of alder and opportunities for short rotation culture. Experience in British Columbia points to the possibilities for capitalizing on the fast early growth of red alder and for improving yield through early thinning (Warrack 1964, Smith 1978a). Short rotation culture is still considered impractical; so in Oregon and Washington general practice is to minimize alder encroachment on conifer sites by application of herbicidal sprays. Yoho et al. (1969) analyzed the economics of converting young alder to Douglas-fir and concluded that in most cases it was advisable to make the conversion. A similar conversion to hemlock-spruce also appears economical and is being accomplished on a large scale in the coastal areas of Oregon and Washington (Dimock et al. 1976a).

Systematic attempts are being made in some areas to select species based on known ecological requirements of tree species and on site conditions. For example, the British Columbia Forest Service is developing guidelines for selection of tree species for use in the Vancouver Forest District based on soil moisture, nutrient regime, and indicator plants (Johnson 1977).

The most productive species may not be the best one to manage if market demand is low. Also, the most productive species may be difficult to manage under harvest cutting restraints imposed by other uses of the area, or a productive species may be particularly susceptible to an insect or a disease. It is up to the forest manager to balance the biological, economic, social, and esthetic factors and decide the best species or species combinations to grow.

OTATION

The optimum rotation age for management of hemlock-spruce depends n the objectives of the landowner. Large industrial holdings usually re managed for maximum economic return. Some small ownerships have his objective, but others are managed for esthetic and recreational alues, shelter for wildlife, or other purposes. On public land a ommon objective is to produce a large yield of high quality sawtimber, nd the rotation age is often set beyond the culmination of the mean nnual increment curve for sawtimber. Almost invariably there is a ix of objectives, so the manager of public lands, faced with overlapping nd often conflicting objectives, must make compromises and select the otation that provides the greatest overall benefits. The manager may ary rotation age from place to place as objectives differ within the wnership--a long rotation for some public use areas and a shorter one or timber production areas.

There is an overall trend to harvest trees at younger ages, but ithin this trend rotations vary widely. At the upper extreme are ecreation areas, often managed under the selection system, where enerally only overmature trees are harvested to maintain esthetic alues and public safety. At the other extreme the private owner, eeding current income, may harvest as soon as the trees are large nough that market value substantially exceeds logging costs. Many emlock-spruce forests are managed as even-aged stands on an economic otation that varies from about 40 years in intensively managed areas o well over 100 years in less accessible areas.

Several factors serve to lengthen or shorten economic rotation ength. Of particular importance is the landowner's alternative rate f return. If it is high, the interest on capital invested in growing tock is high and the rotation is shortened. A high interest rate lso lowers the present net worth of the land, thereby having an pposite but usually lesser effect. Wood value per cubic foot increases ith log size, and large timber is less costly per unit to harvest han small timber; both factors tend to lengthen the rotation by ncreasing the value. Commercial thinning, if gross increment is ittle affected, increases rotation age by concentrating growth on ewer trees and thereby reduces the capital investment in growing tock. Optimum rotations are shorter on good sites than on poor sites Pearse 1966, Grayson and Johnston 1970).

The economic rotation is often adjusted to better coordinate imber production with other uses of the land. A common example is engthened rotations to meet esthetic or landscape management objectives n National Forest land. Other adjustments are made to maintain an even flow of raw material into the local economy, accelerate harvest n decadent stands to capture mortality, produce logs of a particular verage diameter, respond to changing market demand, and meet needs or capital elsewhere in the organization.

Rotation age plays a particularly important role in determining he allowable cut in areas with a preponderance of old-growth timber. he policy on most ownerships has been to extend harvest of overmature tands so that by the time harvest is completed young growth will have eached rotation age and timber harvest may continue without idling tilization plants and disrupting the local economy. Shortening the otation age shortens the conversion period and permits increases in he allowable cut.

Most rotations currently in use on National Forests are termed standard sawtimber rotations and in reality are between a rotation based on culmination of the mean annual increment curve for sawtimber and a strictly economic rotation (McGuire 1976).

TIMBER MEASUREMENT

Meyer (1937) prepared volume tables to be used for spruce and hemlock in Oregon and Washington. These tables remained in use for many years. The spruce tables require entry of diameter data inside bark at 18 ft (5.5 m). This measurement avoids the butt swell in old-growth spruce but is a dimension hard to obtain; the tables are not appropriate for young-growth trees with little butt swell because they tend to overestimate volumes of small trees.

In Oregon, Washington, and Alaska, for many years the USDA Forest Service has used board-foot volume tables based on diameter, total height, and form class (Bruce and Girard n.d., Girard and Bruce n.d.).

Browne (1962) prepared cubic-foot volume tables for British Columbia. The basic tables give total tree volume including stump and top. Supplementary tables provide correction factors that enable the user to derive merchantable volume based on three different utilization standards. Local height curves must be developed before the tables are used for management-unit surveys or timber sale cruises, and it is desirable to develop local corrections for tree form and utilization standards. Corrections for defect must also be made.

Fligg and Breadon (1959), working with a subsample of data collected for the British Columbia cubic-foot volume tables, prepared log-position volume tables for hemlock and spruce. These tables provide cubic-foot volume estimates of individual logs. Also available are tables for conversion of stump diameters to diameter breast high (British Columbia Forest Service 1966).

Volume tables for use in southeast Alaska are available for old-growth western hemlock and Sitka spruce (Bones 1968), old-growth cedar (Farr and LaBau 1971), and for young-growth hemlock and spruce (Embry and Haack 1965, Farr and LaBau 1976). In addition, tables are available for estimating volumes by log positions (Bones 1963) and for estimating diameter at breast height from stump diameter (Bones 1961). Volume tables for old-growth hemlock and spruce in south-central Alaska are also available (Haack 1963).

Johnson and Hartman (1972) reported the development of fall, buck, and scale cruising, in which sample trees are felled and measured in the woods and used to estimate total sale volume. This method eliminates many of the problems of estimating total or merchantable height, tree taper, bark thickness, and defect. The sampling error can be controlled by sample size. Fall, buck, and scale cruising is being used on most timber sales in Alaska.

A major difficulty in timber cruising is estimating the amount of defect in the tree. Defect normally increases with tree age, and its estimation is a problem in the old-growth stands of British Columbia and southeast Alaska. In southeast Alaska, Kimmey (1956) developed factors relating species, diameter, and position of visible indicators

o percentages of decay in standing hemlock, spruce, and cedar. His ables have been revised (Farr et al. 1976). They are useful for xtensive surveys but are often in error for small sales. In British olumbia, tables and equations to predict decay in standing trees have lso been developed (Bier and Foster 1946a, 1946b; Bier et al. 1946; oster and Foster 1952; Browne 1956; Foster 1957).

A recommended approach for determining recovery for hemlock-spruce nd other Pacific Northwest species is to determine cubic volume as ne basic measurement of the available wood fiber, then to convert t to estimates of lumber recovery in board feet, plywood in square eet, chips in tons, and other appropriate end products. Usually ne conversion will require information on diameter and grade of logs nd percentage and type of defect. Conversions to several end products an be made to see which will provide the greatest economic return David Bruce, Pacific Northwest Forest and Range Experiment Station, ersonal communication).

PROTECTING THE SOIL

Productive capacity of the forest ecosystem depends primarily on ne basic soil resource. The soil mantle serves as a storage and egulating medium for water production, provides direct support and nchorage for plants, and serves as a medium for storage and exchange f nutrients. Damage to the soil can directly affect trees through estruction or degradation of the site. Indirect damage to other esources can be even more disastrous.

Care must be taken to protect the physical structure, water- olding capacity, and nutrient capital of the soil through application f proper management practices. In addition, soil classification and apping, along with identification of potential hazard situations, nould be required as part of any timber management activity.

Timber management activities directly affect soils by disturbance uring logging and roadbuilding and through changes in vegetation. orest residues and their treatment and eventual incorporation into ne soil further affect the soil.

The surface of the mineral soil should be protected from the mpact of raindrops and other disturbance. Usually the forest canopy nd the litter layer of needles and small twigs on the forest floor re sufficient protection. When trees are removed during logging, ome of the litter may be scraped away. Depending on the degree of ggregation in the surface soil, exposed soil particles may be dislodged y the splash of raindrops and may plug pore openings. This reduces ne infiltration rate and increases the possibility of surface runoff. urface water picks up still more soil particles which seal off additional ore spaces, and erosion may result. Coastal soils vary widely in rodibility. Exposure that may be inconsequential with some soils may e disastrous with others. Soils developed on recently stabilized eaches, flood plains, and sand dunes are very subject to erosion if xposed.

Forest residues can serve as a substitute mantle, protecting the oil, especially on steep slopes where disturbance is difficult to void and the potential for erosion is great. Part or all of the

residues should be left on such areas to protect the soil. Together with shrubs and herbs, they hold back downhill movement of soil during winter storms.

Residues affect the physical properties of underlying soils. As they decay, the organic compounds in the surface soil often cause aggregation of fine soil particles and this usually improves the water infiltration rate (Rothacher and Lopushinsky 1974). Shade afforded by residues reduces evaporation from the soil surface. Operation of machinery over the surface will, under wet conditions, compact the soil and reduce infiltration rate, permeability, and gaseous exchange. Thus, machine piling of residues to reduce fire hazard or for seedling establishment may also have adverse effects.

EFFECTS OF BURNING ON THE SOIL

Effects on the soil caused by burning residues depend on the kind of soil, intensity and duration of the fire, topography, weather conditions, and many other factors. There is considerable literature on burning effects, but little of it pertains directly to moist hemlock-spruce situations. What does apply mostly concerns the southern portion of the range.

In coastal Oregon, Morris (1970) found that actual exposure of mineral soil after controlled broadcast burning is quite limited. Intensity of burn on sample plots by percentages was: light, 75.2; moderate, 14.2; severe, 0.1; and unburned, 10.5.

After burning, most of the surface is left with a charred but protective mat of organic material to receive the initial impact of raindrops (fig. 39). Morris' study was in the drier portion of the hemlock-spruce range. In the more moist situations farther north, burning is less likely to consume protective forest floor material. Fahnestock examined a 110-acre (44.5-ha) wildfire area on Chichagof Island, Alaska, and found no areas of hard-burned soil.[10/] Rapid development of herbaceous and shrubby vegetation and establishment of tree seedlings provide additional protection throughout the hemlock-spruce type.

Austin and Baisinger (1955) pooled data from moderately burned and hard-burned areas and concluded that burning substantially reduced the organic matter content and moisture-holding capacity of the top 0.5 in (1.3 cm) of soil. Effects were much less in the 2-in (5-cm) layer and insignificant in the 6- to 12-in (15- to 30-cm) layer. Tarrant (1956) also compared physical properties of soil from unburned, lightly burned, and severely burned areas. Soils under lightly burned slash had less macroscopic pore volume, more microscopic pore volume, about the same percolation rate in sandy clay loam, and greater percolation rate in pumiceous sandy loam. Total pore volume and bulk density were about the same. Severe burning had more detrimental effects on soil; but with only 0.1 percent of the soil in this category, the total effect was insignificant. Water-repellent properties of soils may be

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[10/] Fahnestock, George R. 1970 forest residues. Memorandum to the files, August 12, 1970, on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Figure 39.--Broadcast burning generally leaves a charred mat of organic material which receives the initial impact of raindrops and protects the underlying soil from erosion. July, after a spring burn, Oregon coast.

eased by burning, thereby reducing the infiltration rate (DeBano
l. 1970). Light burning apparently has little effect on the
-term geologic process of soil formation (Moore and Norris 1974).

In general, the main physical effect of broadcast burning on
ock-spruce forest soils in the southern part of the range is
eased exposure of mineral soil. This improves the potential
regeneration, also the potential for erosion. But a prescribed
normally exposes only a small portion of the soil, most of the
ct being limited to the forest floor material itself (Morris 1970).
effect can be controlled to some extent by proper timing of the
. Generally, erosion caused by burning of residues is limited to
ial topographic and soil situations. Potential for erosion is
lly highest on steep slopes but may be high on gentle slopes with
ible soils. Soils developed on recently stabilized sand dunes
particularly subject to erosion if the subsoil is exposed.

Burning also affects soil flora and fauna, but specific effects
emlock-spruce forests are little known. Information from other
s indicates that burning causes no major qualitative changes in
osition, and capacity for rapid recovery is great (Jorgensen and
es 1970, Metz and Farrier 1971).

Forest residues serve as a storehouse for an important part of the nutrient capital on many hemlock-spruce sites. Depending on the residue volume and fertility of the underlying mineral soil, they contain variable proportions of the total nutrient supply. The proportion is higher in the north where thick accumulations of mor humus occur, lower in the south where residues decay more rapidly and are incorporated into the soil. Part of the nutrient capital is hauled out of the forest as logs, but the nutrient-rich leaves and twigs are scattered about as part of the forest residue (Cole et al. 1967).

A major effect of burning on nutrition is on timing of nutrient availability for tree growth. Nutrients are released during combustion and, except for nitrogen, most are left in the ash. Subsequent rains leach these nutrients into the soil where, in part, they become available for uptake by plants. Thus, nutrients accumulated over a period of many years are made quickly available. This quick availability is at the expense of slow release of nutrients through decay. Which schedule is more favorable for tree nutrition is not known. The burst of nutrients often contributes to a lush growth of herbs and brush which compete with tree seedlings for light, moisture, and accumulated released nutrients. These nutrients must be recycled and again made available for uptake as trees become dominant and their nutritional demands increase.

Research in other forest types has shown that some of the nutrient capital in forest residues is lost from the site during and after burning. In particular, much of the nitrogen is volatilized during combustion and lost into the atmosphere. This reduces the total amount of the nitrogen capital of the site. Nitrogen concentration of the residual material may be increased because of accelerated nitrogen-fixing activity in the soil, so that after a few years the surface soil may have as much nitrogen as an area that was not burned (Grier 1972, Wells 1971, Jorgensen and Wells 1971, DeBell and Ralston 1970, Knight 1966). This increase, however may be misleading when the long-term effects on the site are considered. Losses of other elements during burning are less. Although some ash is carried away on convection currents during the fire (Knight 1966, Allen 1964, Grier 1972), the greater potential for loss is for nutrients in the ash to be leached or eroded away before they can be utilized by plants. Leaching tends to be more rapid in coarse, sandy soils than in fine soils. Nitrogen also may be lost from a site by leaching, and this increases after burning (Fredriksen 1971).

Calcium and other salts included in the leachate make the soil more alkaline, a condition favoring competing vegetation more than conifers. This alkalinity is short lived, however (Austin and Baisinger 1955, Tarrant 1956). Coastal soils with an average pH of 7.1 immediately after burning averaged 4 years later a near-normal pH of 4.6. This compares with nearby unburned soils where the pH ranged from 4.3 to 4.5 during the same period.

Stephens (1969) found that organic matter rather than clay is the source of almost all the cation-exchange capacity of soils in coastal Alaska. Thus, a reduction in organic matter by burning could have adverse long-term effects on tree growth. On the other hand, Stephens et al. (1969) found that stands that originated after wildfire did not differ significantly in growth rate from stands originating after

ogging. On immature soils--such as alluvium, glacial outwash, or ill--care should be taken to preserve the surface organic layer as a ource of nutrient capital and to reduce erosion.

The main nutritional effects of burning hemlock-spruce logging esidues seem to be increased availability of mineral nutrients and hort-term losses of nitrogen. Burning never adds to the nutrient apital of an ecosystem. It volatizes nitrogen and creates the potential or loss of other nutrients. More research is needed on relationships etween residue treatment and tree nutrition.

OIL MASS MOVEMENT

Landslides are common on steep slopes throughout the hemlock-spruce ype. They are a form of mass wasting or soil mass movement and can classified on the basis of material, depth of movement, and character the failed surface (Sharpe 1938, Eckel 1958). In the hemlock-spruce pe, the most widespread mass wasting includes debris slides, debris alanches, debris flows, and debris torrents. All of these involve itial failure of a relatively shallow cohesionless soil mass on eep slopes above an impermeable layer (Swanston 1974b).

Studies indicate that the critical slope angle corresponding to e average angle of internal friction (angle of repose) for glacial ll soils is 37°. An estimated average critical angle for colluvial ils is 36° (Swanston 1974a). The lower limit of critical internal iction angles for these soils is about 34°. Slopes with gradients ual to or greater than this angle are highly susceptible to slides, rticularly if they are severely disturbed (Swanston 1969).

The angle of repose for soils commonly found on slopes in southeast aska varies from about 34° to 46°, depending on soil density and ight of overlying material (Swanston 1967a). Slope stability is so conditioned by such factors as anchoring by root systems, cohesion ovided by organic colloids, bedrock structure, and moisture content.

Landslide tracks are common throughout southeast Alaska. More an 3,800 large-scale debris avalanches and flows have been counted aerial photographs of the Tongass Forest (data on file, Forestry iences Laboratory, Juneau, Alaska).

Mass erosion was not considered a serious forest management oblem in southeast Alaska before large-scale clearcutting was begun the mid-1950's. Nothing could be done about landslides in the tural environment, and there was no experience to demonstrate what ght happen after extensive logging. After heavy rains in October 1961, vere mass movement occurred in several locations. In Maybeso Valley, mparison of aerial photos taken before and after logging showed that sizable landslides occurred in the 100 years before logging. In ntrast, 116 slides occurred within 9 years after logging (Bishop and evens 1964). As a result, in addition to possible stream siltation, oductive timberland was removed from production. On one study area, percent of regeneration study plots were temporarily or permanently moved from timber production (Harris 1967).

Mechanics of debris avalanching has been described quantitatively (Swanston 1970).

Vegetative cover helps to stabilize steep mountain slopes. When cover is disturbed, the probability of mass movement of soil increases (fig. 40). Damage is extensive as the downslope movement of material often removes all vegetation and soil material in its path. Regrowth may take years as development of new soil is a slow process and sloughing of material may continue in the slide track. Landslides caused by people are also objectionable from an esthetic standpoint.

Extensive investigation of soil mass movement has been done in southeast Alaska (Bishop and Stevens 1964; Swanston 1967a, 1967b, 1969, 1970, 1971, 1974a). In Washington, the effects of landslides and associated siltation of salmon and trout streams has also been studied (Cederholm and Lestelle 1974, Fiksdal 1974).

In western Washington, landslides also occur as a result of heavy rains, often associated with snowmelt. Such heavy runoffs may occur during a chinook, a sudden warm onshore flow of marine air accompanied by heavy rainfall. When they do, severe damage can result. For example, in January 1972 during a 48-hour period, the Longview, Washington, area received over 12 in (30 cm) of rain and a large snowmelt. As a result many slides and much damage occurred (Sommer 1973).

Human activities, such as roadbuilding, play an important part in triggering slides or increasing their frequency. For example, massive failures of sidecast material occurring in May 1971

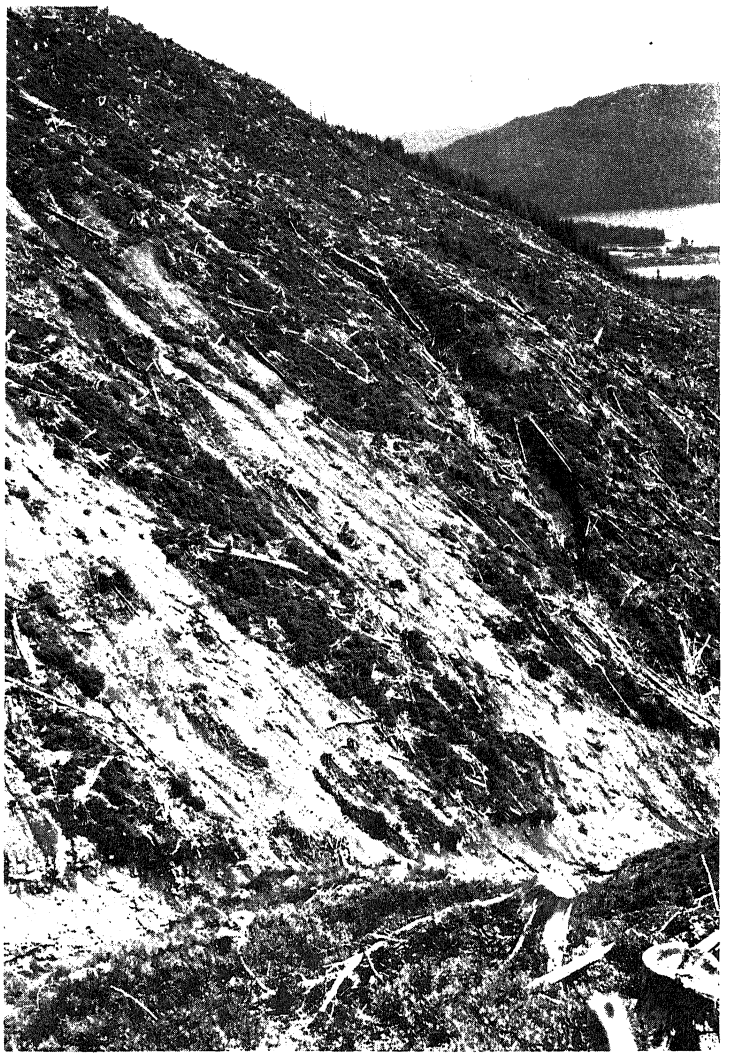

Figure 40.--Soil stability may decrease after clearcutting on steep slopes, such as in this steep V-notch ravine, Maybeso Valley, Alaska.

contributed heavily to the sediment load of Stequaleho Creek, a tributary of the Clearwater River on the Olympic Peninsula, Washington. In this area a study showed that in the previous 84-year period both natural sliding events and those caused by people contributed to sediment in streams. Events caused by people occurred at the rate of 13.3 per year compared with 0.3 per year for natural events. On an annual basis, events related to roadbuilding caused a volume movement of 11,400 yd^3 (8 700 m^3) of material compared with 1,800 yd^3 (1 400 m^3) related to natural events (Fiksdal 1974).

Logging residues can also cause soil loss and stream sedimentation when they contribute to debris torrents. These may be caused when soil material from short debris avalanches in steep gullies accumulates behind logs and debris, forming temporary dams. During high water, these dams can wash out, starting a debris torrent that collects downstream debris and soil as it goes and scours the channel clean for considerable distances. Flows may continue for a mile or more, stopping where the streambed levels off or continuing to deposit material into the next large stream below. On logging areas, accumulation of branches and other residues in stream channels accelerates the process. The problem is most common in areas of high rainfall and in steep "V-notch" ravines (Swanston 1974a, Bishop and Stevens 1964) (fig. 41). Gradient of these streams is usually too steep to allow use by fish; however, debris and sediment may be carried downstream to lower gradient stream sections used by fish.

The most practical management policy has been to avoid logging in areas of maximum susceptibility to slides--that is, slopes of approximate 34° or more (Swanston 1969). Slopes with gradients equal to or greater than this may be highly susceptible to slides, particularly if greatly disturbed. In Alaska, the Forest Service's present policy is to avoid road construction or logging on these areas until methods that do not damage the soil can be developed. Timber on slopes greater than 37° is excluded from the regulated cut[11/].

In the future, it may be possible to safely log on steep, slide-pron slopes. Skyline, balloon, and helicopter logging systems will greatly reduce site disturbance. Whether avoiding soil disturbance will eliminate the problem remains to be demonstrated. Tree root systems may be extremely important in maintaining slope stability. If trees are the major stabilizing force on steep slopes, then clearcutting by any method might still result in significant landslide activity.

The use of alternative silvicultural systems, such as some form of selection or shelterwood, might allow logging on steep slopes. Use of either system might be uneconomic now, especially in Alaska; but a more favorable economic climate in the future could make such timber harvest possible. Before this, however, research is needed to evaluate various alternatives for management of forests on slide-prone slopes. Costs and benefits of various practices should be quantified.

11/ Forest Service Manual R-10 Supplement 126, Title 2400--Timber Management, November 1972.

Figure 41.--Debris-mud flow from a steep ravine, Maybeso Valley, Prince of Wales Island, Alaska: Upper photo, Debris-choked stream channel before flushing; lower photo, debris deposit on gentle topography.

PROTECTING THE FOREST

Trees, like other living organisms, are subject to aging and eventual eath--natural processes in the renewal and continuation of the forest. s individual trees die, they make way for others and their remains are ncorporated into the soil to provide nutrients for future generations. n nature, living (biotic) and nonliving (abiotic) agents alter the atural aging and death processes of trees and stands.

Biotic agents include disease-causing organisms, insects, nematodes, arasitic plants, birds, and mammals including man. Abiotic agents nclude wind, fire, landslides, floods, tidal waves, earthquakes. single agent or a combination of agents may be responsible for a ree's death.

When destructive agents interfere with people's use of the forest, ney become a problem. When forests are managed for timber production, ish and wildlife habitat, recreation, watershed protection, esthetics, r other uses, economic or social loss may result from the natural rocess of forest destruction.

The pattern of death of trees in a stand determines to a large xtent the character of the succeeding forest. For example, when all rees in a stand are blown down, killed by fire, removed by landslides, r clearcut by man, the natural process of renewal usually results in evelopment of an even-aged stand. When individual trees die as a esult of attack by insects, disease, animals, or from selection utting, an all-aged stand tends to follow. Trees decline in vigor s the natural aging process takes place, and the ultimate cause of eath may be difficult or impossible to determine.

Some destructive agents are more important in all-aged climax tands, and others are more important in even-aged stands. The relative mportance of each may change with stand age. Disease is perhaps the east spectacular in visual damage but accounts for much economic loss nrough death of valuable timber and, perhaps of more importance, loss f potential growth that may go virtually unnoticed.

Within the hemlock-spruce type, the importance of destructive gents varies by location. For example, fire is more important toward ne southern portion of the range, especially in drier situations. On ne other hand, fluting, which damages but apparently does not kill estern hemlock, is restricted to the northern portions of the type.

Silvicultural techniques used to manage stands can influence the usceptibility of trees and stands to damage by various agents. ne forest manager should take this into account and must be aware of otential damage and be ready to adjust management techniques as xperience dictates. An excellent review of forest protection as it elates to western hemlock is available (Hart and Driver 1970).

A discussion of some damaging agents of the more important com- ercial tree species within the hemlock-spruce type follows. They ary in importance and amenability to management. For example, infection y dwarf mistletoe causes loss of growth on hemlock, but it can be ontrolled through proper silvicultural practices. Wind also causes erious losses which can be reduced but not entirely prevented.

Damaging agents will be discussed in various detail, depending on importance, available knowledge, and degree to which silvicultural practices may prevent losses.

FIRE

Fire can be a serious destructive agent within the hemlock-spruce type, but far less serious than it is farther inland. Greatest danger from fire is in the south. In Oregon, Washington, and on Vancouver Island fire danger increases rapidly inland from the beach, coincident with reduced summer fog. Aspect also affects fire danger. In many valleys oriented east and west, south-facing slopes have experienced a higher frequency of fire than the north-facing slopes (Schmidt 1960).

Fire has affected both species composition and age structure of the coastal forest. Where fire has been common, extensive even-aged stands are found, many dating from fires caused by people during the period of white settlement. In contrast, Alaska hemlock-spruce forests are generally older and uneven-aged, although extensive even-aged stands do occur.

Fire is an important factor in controlling the distribution of Douglas-fir, and the species is likely to be a more important component of coastal forests in areas having frequent fires. The absence of Douglas-fir on the coast north of Kemano, B.C. (lat. 53°30'), appears to be owing to infrequent fires (Schmidt 1960).

Extensive fires have occured within the hemlock-spruce type. Morris (1934) has provided a good summary of recorded fire history for western Washington and western Oregon from the early 1800's to the Tillamook fire of 1933. During this period, fire was a common occurrence. Much of the area was uninhabitated, and reburns were common. It is difficult to reconstruct an exact fire history, but certain years stand out as especially severe. Particularly destructive fires occurred between 1845 and 1849 in Oregon's Nestucca Bay area and elsewhere in Oregon. In 1868 an extreme number of fires burned from Oregon to British Columbia. Schmidt's (1970) history of presettlement fires on Vancouver Island also reveals a long sequence of major fires. Much of this area, however, lay outside the hemlock-spruce type.

Fires on the Queen Charlotte Islands, British Columbia, have been mainly confined to rain-shadow areas on the eastern portion of the islands, receiving less than 60 in (150 cm) of annual precipitation.[12/]

In southeast Alaska, extensive fires have occurred in the past; but since 1900, few have been larger than 100 acres (40 ha). Fire does not play an important role in the management of coastal Alaska's forests. Summers are generally moist and cool; dry periods last only a week or 10 days. Dry periods of 2 weeks or more with above normal temperatures occur every few years; but during recent dry summers, there have been few large fires. Lightning is rare in coastal Alaska, and fires are almost entirely caused by people. Permanent residents, transients, recreationists, contractors, and others share the responsibility (Noste 1969).

With low fire risk, it has not been necessary to burn logging residues. Most fires occur in connection with logging or logging

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12/ Personal communication from R. L. Schmidt, B. C. Forest Service, Victoria.

camps, and operators are required to maintain fire equipment at all times. During occasional summer dry periods, they may be required to alter working hours or suspend work. On National Forest lands in Alaska, limiting clearcuts to 160 acres (65 ha) further reduces hazards.

The Forest Service does not maintain a fire-suppression force in coastal Alaska, but standing agreements permit rapid airlifting of crews and equipment from the lower 48 States and interior Alaska if needed. As more use is made of the forests in coastal Alaska, the risk of fire will increase. Disastrous fire years will no doubt occur in the future as they have in the past.

Fire danger from accumulation and exposure of forest residues is of definite concern in the hemlock-spruce type, although less so than in drier forest types. The greater concern is in the southern part of the range. Throughout the range, however, there is always a danger of wildfire starting in forest residues.

In Oregon and Washington, fire has been an important consideration in management of the hemlock-spruce type, particularly inland in the transition zone toward hemlock or Douglas-fir forests. Slash burning to reduce fire hazard has been the rule wherever conditions were dry enough to permit burning. Now, however, decisions to burn tend to be made to fit individual circumstances. Often the need to reduce hazard is less today because of better utilization and harvesting small cutting units. The problem of pollution from smoke has caused a reevaluation of the need for burning. Fire regulations in each State and most timber sale contracts require felling of snags and unmerchantabl trees on clearcut areas, primarily to reduce fire hazard.

Public land managers are often faced with increased fire risk due to heavy public use, and this has tended to favor burning. Private landowners may simply restrict use of their land during periods of high danger.

Generally in the hemlock-spruce type in Oregon and Washington, the trend is away from slash burning because of better utilization, more cutting in young even-aged stands with less defect, problems with air pollution, and the greater value of western hemlock and, hence, less conversion to Douglas-fir.

ANIMAL DAMAGE

Mammals and some birds destroy seeds and damage trees and stands within the hemlock-spruce type. In the unmanaged forest, the influence of mammals is merely part of the normal ecological process. In some cases people may place a higher value on the animals involved than on the trees or other plants "damaged." This fact is becoming especially important as demand for outdoor recreation increases; however, when forests are managed for production of wood, fiber, or other products derived from trees, animal damage may become a problem (Crouch 1969, Black et al. 1969, Dimock and Black 1969). Evans (1969) has reviewed damage from wildlife as it affects management of western hemlock.

Mice, voles, and shrews of various species are common on forested and cutover land throughout the hemlock-spruce type (Klein 1965, Manville and Young 1965, McGregor 1958, Meehan 1974, Moore 1940).

Although they were considered a potential problem at one time (James 1956), they have apparently not prevented natural regeneration on cutover areas (Harris 1968). They do consume considerable amounts of tree seed and where they cannot be controlled by pesticides have largely eliminated direct seeding as an artificial regeneration practice.

In British Columbia, damage from squirrels gnawing the inner bark of western hemlock has been reported (Buckland 1952). Usually squirrel damage is restricted to small areas, but in one case some 5,700 acres (2 300 ha) on Tournour Island in Johnson Strait were affected. Trees from 8 to 80 years old were damaged. Complete girdling was rare, but decay is reported to have entered through 30 to 70 percent of scars.

Both elk and deer damage trees within the hemlock-spruce type, but little specific information is available on extent of damage. Elk browse conifer seedlings and may damage plantations by trampling seedlings while grazing on clearcut areas. According to Harper (1968), damage peaks from 6 to 8 years after logging and lessens thereafter. Damage is greatest near timber and diminishes as the distance from standing timber increases. Elk have apparently eliminated some plant species in creek bottoms on the Olympic Peninsula and undoubtedly play an important role in plant succession on alluvial bottom-land sites (Franklin and Dyrness 1973, Sharpe 1956).

According to replies to questionnaires from Forest Service land managers, deer are the most troublesome animals on National Forests in the Pacific Northwest (Crouch 1969). Deer readily browse conifer seedlings. Browsing slows the growth of seedlings and may kill young or newly planted seedlings (Black et al. 1969).

Species preference is not clearly known. In some areas of western Washington and Oregon, browsing by deer has retarded Douglas-fir and allowed western hemlock to dominate the sites (Mitchell 1950). Cowan (1945) reported that deer preferred Douglas-fir over western hemlock and suggested planting hemlock in portions of southern Vancouver Island where browsing was a problem. On the other hand, Brown (1961) found that western hemlock was preferred over Douglas-fir. Western redcedar appears to be preferred in the Queen Charlotte Islands to the point where cedar regeneration has been eliminated in some locations. In Alaska browse preferences are not known and deer are not now considered a problem in reforestation.

Efforts to control damage involve use of barriers that prevent browsing or use of chemical repellants that discourage browsing. Plastic mesh tubing (Campbell 1969, Campbell and Evans 1975) is being used to protect Douglas-fir seedlings in Oregon and Washington with some success (fig. 42). Chemical repellants have been tried over the years with varying success (Evans 1974, Rochelle et al. 1974).

Some protection from browsing may be obtained by leaving logging residues on the ground rather than burning them (Crouch 1968, Gockerell 1966). Planting of very large seedlings--up to 5 ft (1.5 m) in height--may reduce their susceptibility to browsing (Hartwell 1973, Hines 1973); and when browsed, large seedlings may recover more readily than small ones (Newton 1973). Selection of less palatable genotypes shows promise (Dimock 1974, Dimock et al. 1976b).

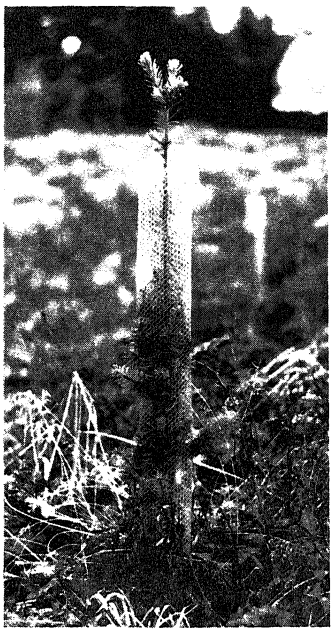


Figure 42.--Plastic-mesh tubing on Douglas-fir seedling to protect it from browsing. Quinault, Washington.

gure 43.--Inspection of ouglas-fir branch clipped y mountain beaver, Quinault, ashington.

Increasing the size of clearcuts may reduce damage. Smith and Walters (1965) noted that damage to planted Douglas-fir on Vancouver Island was concentrated in clearcut areas that seldom exceeded 2 acres (0.8 ha).

Mountain beavers (*Aplodontia rufa*) or "boomers," as they are known locally, are an important cause of damage to conifer plantations in portions of the hemlock-spruce type (Munger 1943, King 1958, Crouch 1969, Lawrence et al. 1961). The animals range along the Pacific coast from northern California to British Columbia. The mountain beaver is unrelated to the more common bank beaver (*Castor*). It is the lone representative of a primitive family found only on the Pacific coast (Ingles 1965).

Damage from mountain beavers has been described by Lawrence et al. (1961). It includes stem clipping of small seedlings, branch cutting, and basal girdling. Lateral branches may be clipped from saplings up to a height of 10 ft (3 m) or more. The animals sometimes leave short branch stubs which may aid them in climbing (fig. 43). Bark is often stripped from trees, similar to damage by bears, but horizontal toothmarks and irregular claw marks distinguish this work from damage by bears. When small seedlings are clipped, the damage may be indistinguishable from damage by rabbits. In addition to damage in newly established stands, damage may occur after precommercial thinning (Waterman 1976).

Control of mountain beavers is difficult and expensive. A method of poisoning by use of toxic tracking foam has been developed (Martin 1969, Oita 1969), but restrictions on the use of poisons prohibit its use in many areas. Trapping is done in areas with dense populations and currently is the principal control method.

Porcupines damage trees by feeding on inner bark and foliage (fig. 44). They are not common in hemlock-spruce forests of Oregon and Washington. In Alaska they are found throughout the hemlock-spruce type, both on the mainland and on many offshore islands (Meehan 1974). Although porcupines damage both western hemlock and Sitka spruce, they have not been considered a serious pest in old-growth stands. As young, even-aged stands come under more intensive management they may become troublesome (Evans 1976). Little is known about numbers or extent of damage, although in very localized areas nearly every dominant tree may be damaged.[13/]

Figure 44.--Porcupines damage young hemlock and spruce trees in Alaska by girdling stems. This is not a problem in the Pacific Northwest.

Methods of controlling porcupines include hunting, trapping, and use of poison bait (Lawrence 1957). Porcupines' craving for salt allows the animals to be attracted to poison-bait stations; if used improperly, however, pesticides are capable of harming other forms of mammalian life (Hooven 1971).

Snowshoe hares (varying hares) damage seedlings within the hemlock-spruce type in Oregon and Washington (Canutt 1969, Lawrence et al. 1961),

[13/] T. L. Thompson. Porcupine damage--Prince William Sound. Memorandum to Chugach National Forest, 10/16/73, on file at Forestry Sciences Laboratory, Juneau, Alaska.

rimarily by clipping terminal shoots of seedlings up to 10 in (25 cm) all. Trees clipped repeatedly are sometimes little more than small ushes. Leaders often escape beyond reach, however; and then damage s no longer a problem.

Snowshoe hares are present on the mainland of coastal Alaska and ave been introduced on some islands. They damage or destroy Sitka pruce seedlings and young saplings.[14/] Little is known about their opulation levels and the extent of damage caused, and no effort at ontrol is being made in Alaska.

Various methods of reducing numbers of snowshoe hares with toxicants ave not provided adequate protection for seedlings and have been azardous to nontarget species. Two possible control methods are lanting seedlings large enough to resist destruction and destroying abitat by land scarification (Hartwell 1969).

Brush rabbits damage seedlings in Oregon, but their range does ot extend northward into Washington (Canutt 1969).

In western Washington, black bears often damage young trees by tripping bark and girdling to reach the tasty cambium layer (Poelker nd Hartwell 1973) (fig. 45). Damage may occur from ground level to a height of 50 ft (15 m). Bears apparently prefer to work on thin bark (Childs and Worthington 1955, Levin 1954). Greatest damage has been reported on Douglas-fir; but western hemlock, western redcedar, and red alder are also attacked. Differences in chemical constituents within tree bark have been suspected in bears' preference for particular tree species, but chemical analysis alone has not been sufficient to explain feeding preference (Radwan 1969).

In southeast Alaska, brown bear sometimes damage Alaska-cedar trees by stripping bark. Such trees are not girdled and usually survive. The resulting catfaces are common on Alaska-cedar in some areas.

Figure 45.--Bear damage to Sitka spruce. Clallam County, Washington.

14/ Tom L. Thompson. Reconnaissance report on natural reforestation of Woody sland clearing problems relating to varying hare and the implications to Afognak sland. Report dated May 24, 1974, on file, Forestry Sciences Laboratory, Juneau, aska.

Bank beaver cause minor damage to hemlock, spruce, and associated species throughout the type. Observations on the islands of British Columbia between Queen Charlotte Sound and Dixon Inlet show that beaver prefer western hemlock to alder for food (McCabe 1948).

In Alaska, beavers commonly cut young spruce, cottonwood, alder, and hemlock for food and for construction of dams. Damage from tree cutting is restricted to the immediate vicinity of dams. More serious damage occurs from flooding caused by blocking of culverts. When flooding threatens to cause damage, beavers can be removed by trapping or by installation of fencing or "beaver bafflers" at the ends of culverts. The latter solution is often preferred because the presence of beavers can add to public enjoyment of recreation areas.

In addition to the animals mentioned, the red-breasted sapsucker (Ziller and Stirling 1961, Bent 1939), red squirrels (Meehan 1974), and probably many other creatures influence hemlock-spruce forests to some extent. As management intensifies, a thorough evaluation of wildlife damage throughout the range will be necessary.

In the past, efforts to reduce animal damage have emphasized direct control of wildlife by hunting, trapping, or poisoning. These direct methods too often have been unsuccessful or have caused serious side effects. More recently, emphasis on reducing damage by animals is shifting toward greater consideration of habitat management and less on direct control (Hermann 1969).

INSECTS

Most insect species in the hemlock-spruce forests feed on dead organic material. This hastens its breakdown and the release of nutrients for plant growth. Others are parasites or predators that help to regulate population levels of destructive insects. Insects provide food for fish, animals, and birds. Even insects that are destructive to individual trees may benefit the old-growth forest ecosystem through their influence on stand structure. Insects and their tree hosts have evolved together in the virgin forest ecosystem. Insects become a problem when they compete with human activity.

As more old-growth stands are logged and forests converted to intensively managed, even-aged stands, the same level of insect damage may be unacceptable. Insects considered innocuous in virgin stands may then become serious pests (Silver 1962), and some form of suppression may be necessary (Mitchell 1970). Alternatives for pest management may include the use of chemicals, biological controls, and silvicultural practices designed to minimize the problems (Hard 1974b).

Most insect damage is caused by defoliators. In British Columbia the most destructive defoliators have been the western hemlock looper, the black-headed budworm, the saddle-backed looper, and the spruce budworm. Where Douglas-fir is present, it may be attacked by a number of defoliators, beetles, and aphids (Mitchell 1970). A seedling weevil has caused damage in Douglas-fir plantations and natural spruce regeneration (Lejeune 1962).

In coastal Alaska the black-headed budworm and the hemlock sawfly re, in order, the two most destructive forest insects (Hard 1967). estern hemlock is the preferred host of these defoliators, although itka spruce may also be attacked. Population levels appear to be elated to weather (Silver 1960, 1963; Schmiege 1966; Hard 1974a).

Outbreaks of the black-headed budworm and hemlock sawfly often ccur together. Frequently, a succession of outbreaks begins in the lympic Peninsula or southern British Columbia and progresses north to he Queen Charlotte Islands, southeast Alaska, and Prince William ound. This northerly progression might be accounted for by the ncreasing time required for development toward the north associated ith decreased temperatures during the growing season (Hard 1974b).

Other defoliators, as well as bark beetles, are present in coastal laska at endemic levels, occasionally undergoing population buildups nd causing local damage. Relatively few insect species, however, are estructive to the old-growth forests of southeast Alaska. Weather uring the growing season appears to be a major limiting factor in heir activity (Hard 1974a).

The spruce aphid, a sap-sucking insect, defoliates and kills Sitka pruce from California to Alaska. It is a serious pest of ornamental rees. The insect can reproduce throughout the year, so mild winters avor population increases. Epidemics are sporadic and short lived Furniss and Carolin 1977). The insect has recently been active and s causing considerable damage from Oregon to Alaska on trees near the pen sea.

Hemlock and spruce residues rarely contribute to a buildup of nsect populations that attack living trees. Forest residues harbor mbrosia beetles which readily attack felled and bucked timber and rees felled by the wind or by other damaging agents. They cause ittle or no damage to pulp timber but often seriously degrade saw ogs or veneer logs. Ambrosia beetles and other insects provide entry ourts for disease organisms which, in turn, speed decay of residues Mitchell and Sartwell 1974).

In Alaska a localized outbreak of spruce beetle occurred in 1941 nd lasted several years. Origin of the infestation was thought to ave begun in windthrown timber or in overmature live trees during an bnormally dry period (Hard 1974b). Although it is possible for this nsect to build up in logging slash, experience has not shown this to e a serious problem.

The white pine weevil is the most serious enemy of young Sitka pruce in Oregon, Washington, and British Columbia (Wright 1970, ilver 1968) (fig. 46). It is not a problem on the Queen Charlotte slands or in southeast Alaska, where temperatures may be too low to llow the insect to reproduce (McMullen 1976a, Gara et al. 1971). ithin its range the white pine weevil is more damaging on drier sites ocated inland away from the coastal fog belt (McMullen 1976b, Overhulser t al. 1974). Before logging, many of these sites supported excellent ld-growth stands of spruce. These stands may have escaped weevil nfestation for one reason or another or may have survived numerous eevil attacks during their early years. Given time then, such sites re suitable for spruce. Under management, however, a merchantable

caused by weevil infestation limits the suitability of these sites for future management of Sitka spruce. These sites are probably outside the practical range of Sitka spruce and, until weevil-resistant strains are developed, they should not be planted with spruce. In fact, under current management, weevil infestation is so severe in some areas along the Oregon and Washington coast that Sitka spruce is no longer planted.

Research is underway to find or develop weevil-resistant varieties or strains of Sitka spruce. In Oregon, a 15-year test of susceptibility to weevils showed that Lutz spruce, a naturally occurring hybrid between Sitka and white spruce on the Kenai Peninsula, Alaska (Little 1953b), was the most promising replacement (Mitchell et al. 1974).

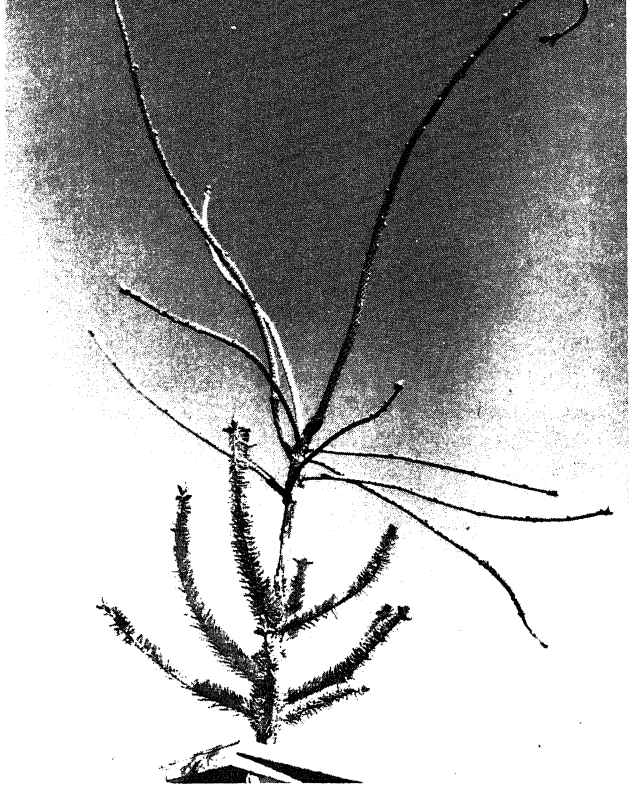


Figure 46.--Weevil damage to Sitka spruce. Photo taken in May showing the dead top of a tree that had been attacked a year earlier. Clatsop County, Oregon.

A survey of insect activity is conducted annually in Oregon, Washington, and Alaska by the USDA Forest Service. Results of the surveys are published yearly by the U.S. Department of Agriculture in a series titled, "Forest Insect and Disease Conditions in the United States." A similar survey is carried out annually in British Columbia by the Canadian Forestry Service, with annual reports by district published by the Pacific Forest Research Centre, Victoria, B.C. Over the years these reports are adding substantially to our knowledge of insect activities. In addition, there is a need to quantify the damage caused by insects, to evaluate the relative importance of insect problems within the hemlock-spruce type, and to establish costs and benefits of various alternative methods of controlling insects.

FLUTING

Fluting, or the presence of deep vertical grooves in the main stem of western hemlock, is a problem in Alaska (Harris and Farr 1974). The extent of area affected within the hemlock-spruce type is not known, but severity decreases southward. We have noted occasional hemlock with slight fluting as far south as Vancouver Island. Fluting is rare in Washington and Oregon. Fluting is particularly

noticeable in some even-aged stands (fig. 47); the agent or mechanism that triggers its development is not known.

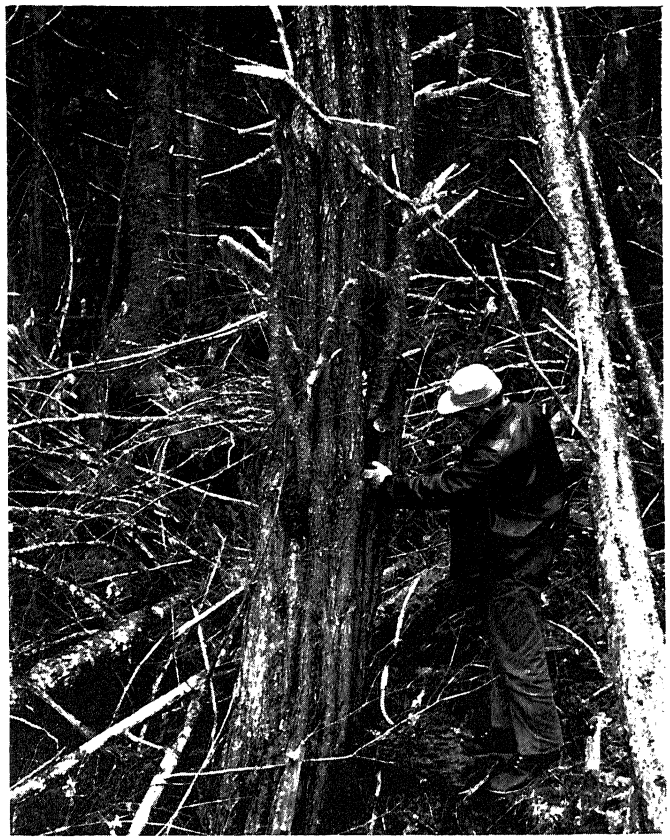


Figure 47.--A badly fluted western hemlock in an even-aged stand, Prince of Wales Island, Alaska. Fluting decreases pulp yield and can make trees unsuitable for sawtimber. Sitka spruce is not affected.

In southeast Alaska, seriously fluted stands occur over the range of sites. Some second-growth stands are so badly affected that the hemlock component is of no merchantable value for sawtimber (Alaska Forest Research Center 1957, p. 24-25). Ingrown bark can be separated from the wood in pulping, but the process is more costly, and there is less cubic-foot volume in fluted logs. Spruce apparently is not affected. A fluting problem affecting Sitka spruce has received attention in Britain (Day 1958, 1964). Day (1964) suggested that development of flutes may be due to problems of water transport and supply within the stem, as influenced by the condition of the root system and the demand made by the crown.

Intensive management of second-growth stands in Alaska could be influenced by knowledge of the cause of fluting of hemlock. Soil, stand density, root disease, frost, or genetics might be responsible. A detailed study of the problem is needed.

FOREST DISEASES

Both biotic and abiotic agents contribute to forest diseases. In hemlock-spruce forests the most important biotic agents are dwarf mistletoe, a parasitic plant, and the fungi that cause wood decay, needle cast, cankers, death of shoots, and wood staining. Abiotic agents include heat, freezing, drought, flooding, mechanical damage, and air pollution. Often there is an interaction--for example, drought-stressed trees may be more succeptible to pathogens; wind-broken tops serve as entry courts for decay fungi. An excellent source of information on diseases of forest trees is available (Hepting 1971).

Most organisms that cause disease are endemic in hemlock-spruce forests, and many are beneficial. Wood-destroying fungi are essential for breaking down and recycling nutrients contained in the stems, limbs, and foliage of fallen trees.

Although some of the slash-inhabiting fungi also attack living trees, their presence in logging residues does not greatly increase

the risk of infecting the residual stand. Inoculum is already present from other sources in the forest, and rate of infection is governed mostly by occurrence of entry courts in living trees rather than absence of inoculum (Childs 1939, Aho 1974). Fungi that cause root rots--such as *Fomes annosus*, *Phellinus* (*Poria*) *weirii*, and *Armillaria mellea*--however, survive as saprophytes in stumps and roots after a tree is harvested and may spread through root contact to residual trees (Nelson and Harvey 1974).

Loss of productivity from disease may be almost unnoticed. The loss is not spectacular as with insect epidemics, blowdown, or fire. Fire may be the most spectacular; yet over a rotation, disease may cause far greater loss of timber--perhaps more than from any other damaging agent. Decay, caused by heart- and root-rotting fungi, is probably the greatest single cause of loss of volume in the forests of southeast Alaska (Laurent 1974).

Losses from decay fungi in Alaska are high, principally because of the old-growth structure of the forests (fig. 48). About 31 percent of the gross board-foot volume in old-growth stands is estimated to be unusable as sawtimber.[15/] Conifers up to 100 years old have little decay. Thereafter, the probability of a tree having rot increases rapidly. By 200 years, 65 percent of the cedar, 50 percent of the hemlock, and 20 percent of the spruce contain some rot (Kimmey 1956).

Defect varies greatly within and between tree species. For example, in Alaska, defect in old-growth Sitka spruce averages about 9 percent of total gross volume; in western hemlock, about 22 percent; and in the cedars, about 52 percent (Hutchison 1967).

In Oregon and Washington, Englerth (1942) found that in western hemlock the four most important decay organisms were: *Fomes annosus*, causing 21 percent of the board-foot decay; *F. pini*, 19 percent; *F. applanatus*, 17 percent; and *F. robustus*, 10 percent.

In the Queen Charlotte Islands, total loss from decay of western hemlock was 25 percent of the gross volume (Foster and Foster 1951). Most losses were in older and larger trees; no single fungus caused loss of more than 2 percent of gross volume.

In Alaska the brown rots account for 84 percent of the decay

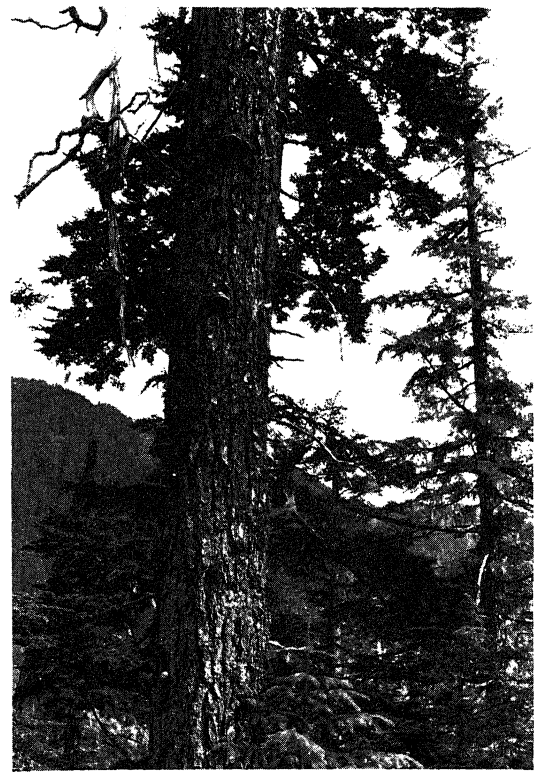


Figure 48.--Diseases of the tree stem caused by fungi are common in Alaska. Conks on this old-growth western hemlock near Juneau indicate that the tree contains extensive rot.

15/ Forest Survey Statistics on file, Forestry Sciences Laboratory, Juneau, Alaska.

itka spruce. The white rots account for 68 percent of the decay estern hemlock and 98 percent in western redcedar. *Fomes pinicola*, own rot fungus, causes 74 percent of the decay in Sitka spruce and ercent in western hemlock. In western hemlock, the white rot i *Armillaria mellea* and *Fomes annosus* account for 20 and 22 percent he decay. The white rot fungi *Poria albipellucida* and *Phellinus ia*) *weirii* account for 46 and 41 percent of the decay in western edar (Kimmey 1956).

In old-growth stands, little can be done to reduce defect or ase. Cutting priorities, however, first should be to remove the decadent stands occupying productive sites. Conversion from old th to vigorous young growth has great potential for reducing decay. rot problems, however, are becoming more apparent in young growth. reduce growth and vigor and are important in management of young- th stands.

Infection by *Fomes annosus* from old stumps to new seedlings can to serious damage in hemlock plantations. A study in western ington showed the presence of some infection before thinning in ern hemlock stands 20 to 60 years of age. After thinning, a tively high rate of stump infection (50-90 percent) was found, cating a high potential for stand infection during the remainder he rotation (Driver and Wood 1968). This pathogen destroys lignin he wood, but cellulose is largely unaffected. The base of the t log may be destroyed for lumber recovery but still be usable for . Treatment of stumps with chemicals immediately after cutting help to prevent infection (see page 73). The thin bark and low roots of hemlock and spruce make them particularly susceptible ogging injury. Bark and root scarring can lead to serious decay, cially in hemlock (Buckland et al. 1949; Foster and Foster 1951; ht and Isaac 1956; Shea 1960, 1961; Wallis et al. 1971).

In the late 1960's a stem disease, identified as *Sirococcus bilinus* (Funk 1972) (fig. 49), was first noted in stands of young- th hemlock in Alaska. The disease causes dieback of the tip and ral branches and kills some trees. The potential for damage is known, but one survey suggests that damage to managed stands is ht (Wicker et al. 1978). Research is needed to evaluate the nism in Alaska.

Air pollution may damage forests in localized areas. In Alaska, ur oxide emissions from two pulpmills have injured and killed a spruce, western hemlock, western redcedar, and Alaska-cedar. In case trees on approximately 400 acres (160 ha) were killed rent 1974).

Hemlock dwarf mistletoe is an important disease of western hem- (Baranyay and Smith 1972, Childs and Shea 1967, Russell 1976, and Stewart 1972). Mistletoe can best be controlled as mature ds are harvested. Silvicultural practices designed to control f mistletoe can be included in management plans, often at little tional cost, as discussed in the following section.

Dwarf Mistletoe Control

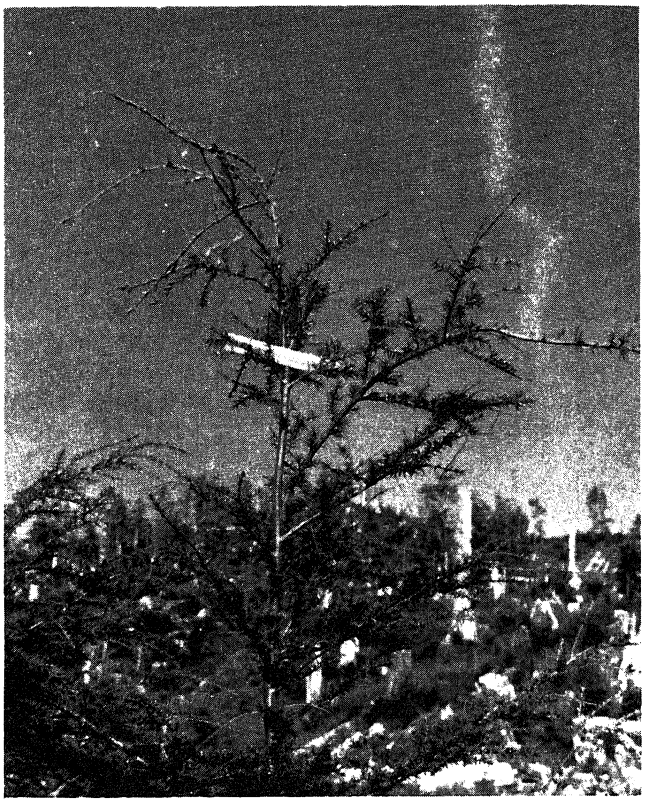


Figure 49.--A stem dieback of western hemlock caused by Sirococcus strobilinus *is common in some young hemlock-spruce stands in southeast Alaska.*

Western hemlock is susceptible to infection by hemlock dwarf mistletoe throughout the Sitka spruce-western hemlock type as far north as Haines, Alaska (Hawksworth and Wiens 1972). Infections usually occur in a patchlike distribution, apparently correlated with stand history. Annual loss of growth and reduction in wood quality are not accurately known, but hemlock dwarf mistletoe certainly is a factor affecting financial returns from coastal old-growth forests. It disrupts the normal development of the tree by causing stem swellings, gall-like growths that weaken the stem, brooming of branches, and variations in wood density. It provides entry points for decay organisms through broken stubs or old brooms and patches of dead tissue over infected areas. Rate of height growth is reduced and then diameter growth as the intensity of infection increases. In dense stands, infected trees tend to be overtopped and die; in open stands they remain to become severely deformed (fig. 50). Many trees are killed outright by severe mistletoe infection. Others are weakened and later succumb to decay organisms, insect attack, or wind.

Dwarf mistletoe can be controlled by silvicultural treatment, and often this should be the first step in bringing a stand under intensive management.

There is a large body of literature on dwarf mistletoes; most of it is on the pines, but control recommendations are generally applicable to hemlock. In recent years more emphasis has been on hemlock. The literature was reviewed by Gill (1935), Kuijt (1955), Gill and Hawksworth (1961), and Hawksworth and Wiens (1972). Recommendations for control were prepared by Graham (1967), Russell (1976), and Baranyay and Smith (1972). Research specifically on hemlock dwarf mistletoe has been reported by Buckland and Marples (1952), Shea (1966), Smith (1964, 1966, 1968, 1969, 1971, 1973, 1977), and Wellwood (1956). The following background information and examples of control procedure are mainly based on these reports.

Figure 50.--Dwarf mistletoe on western hemlock, southeast Alaska.

Within the hemlock-spruce type, western hemlock is the principal host of hemlock dwarf mistletoe (Russell 1976). Sitka spruce is essentially free of the disease, with only a few reports of infection--Chichagof Island, Alaska (Laurent 1966), Kitimat, British Columbia (Molnar et al. 1968), and southern Vancouver Island.[16] Infection of hemlock dwarf mistletoe has been collected on mountain hemlock in British Columbia (Ross et al. 1973). Infection has been reported in Alaska (Weir 1915) but has not been substantiated by recent collections.[17] Secondary hosts include shore pine, Pacific silver fir, subalpine fir, and white pine. Douglas-fir and western redcedar are resistant to the disease (Baranyay and Smith 1972).

[16] Personal communication from R. B. Smith, Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B. C., 1977.

[17] Personal communication from Thomas L. Laurent, USDA Forest Service, Juneau, Alaska, 1978.

Background Information

Dwarf mistletoes are flowering, seed-bearing plants with endophyt systems or "roots" that invade woody tissues of host trees. Dwarf mistletoes produce a fruit with an explosive seed-dispersal system that can expel seed at initial velocities well over 50 ft (15 m) per second. As the berry matures, its stem is recurved so the top of the berry points downward; viscin cells between the seed and the berry's hull absorb water, creating a high internal pressure. When the fruit drops from the stem, the hull rapidly contracts, ejecting the seed upward and outward. Seeds are coated with a mucilaginous substance (viscin), enabling them to adhere to the surface of the host. Dispers distance ranges up to 50 ft (15 m), but most seeds land within 30 ft (9 m) of the source plant (Smith 1973). Dispersal can be increased somewhat by storm winds and steep slopes.

Some seeds land on susceptible twigs; but because of the much greater target area, most are intercepted by needles. These must move to susceptible woody tissue by gravity, washing by rain, or other means to cause infection. A study on Vancouver Island showed that of seed dispersed from mistletoe in an infected residual tree, 37 percent attached firmly to nearby hemlock seedlings and 13 percent caused infection (Smith 1977).

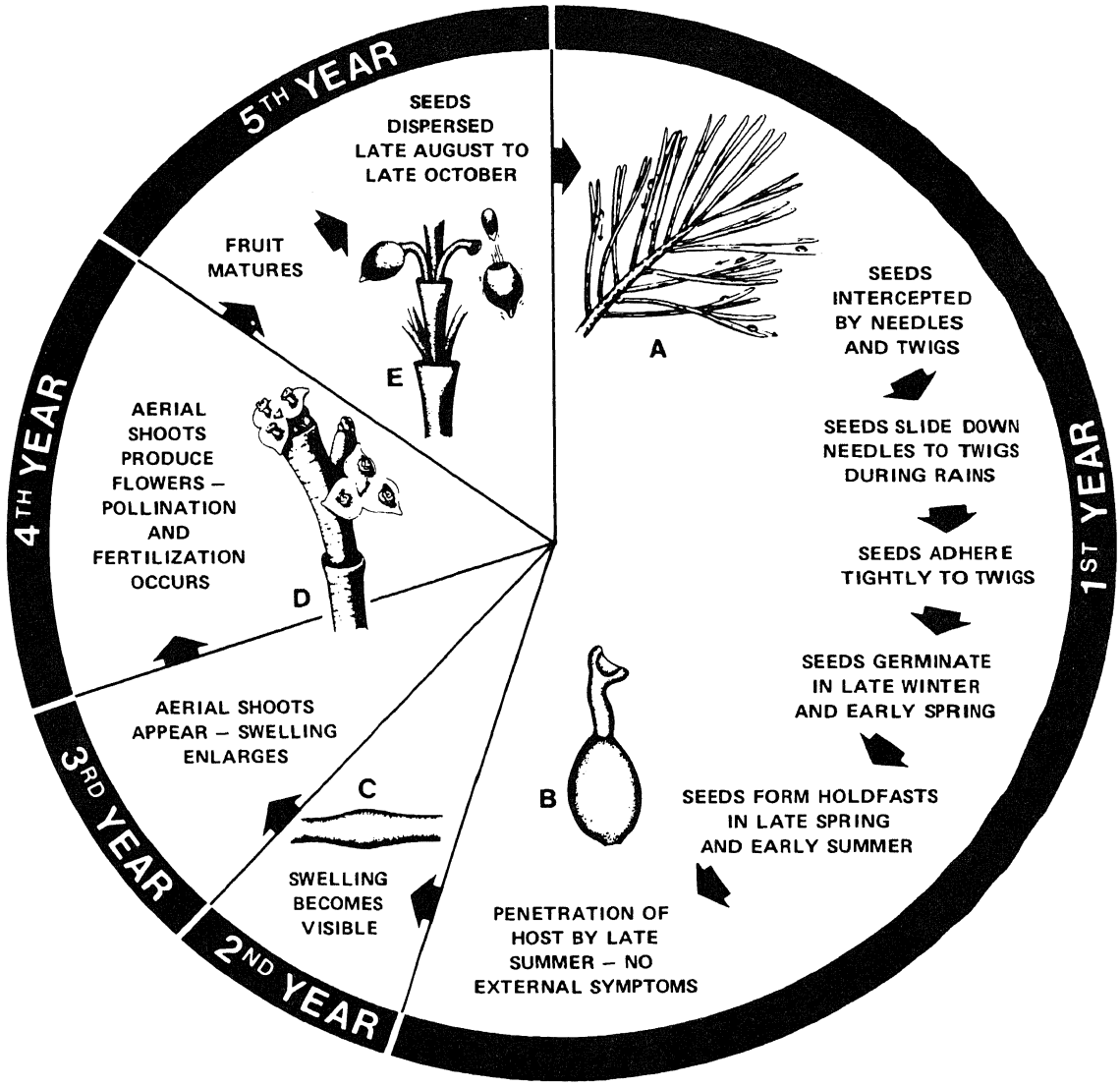
The ecology of dwarf mistletoe seed is well documented (Wicker 1974). Seed germinates in late winter or early spring, a mound of tissue or "holdfast" is formed, usually at the base of a needle, and infection of the host is initiated by means of a penetrating structure developing from the holdfast. This ends the brief self-sustaining phase of the dwarf mistletoe plant; thereafter, it is largely parasiti

Growth of the endophytic system and associated hypertrophy of host tissue forms a characteristic fusiform or spindle-shaped swelling which is the first outward sign of infection (fig. 51). Aerial shoots

Figure 51.--Spindle-shaped swelling of branches is usually the first sign of hemlock dwarf mistletoe infection.

are produced 2 or more years after penetration. Shoots range up to 5 in (13 cm) long and have rudimentary green leaves appearing as small scales at the internodes and lending a segmented appearance to the shoot.

Flowers develop in late summer and are pollinated mainly by insects. Fruit matures in the fall of the succeeding year. Dwarf mistletoe is dioecious, with male and female plants located at different infection points. Total life cycle, or the period from infection by seed to production of seed, is from 4 to 8 years (fig. 52)--an important point to consider when planning control measures.



Generalized life cycle of dwarf mistletoe:

A. Needle angles as they affect dwarf mistletoe seed movement.
B. A fully developed dwarf mistletoe seedling with holdfast.
C. Small branch swelling is the first indication of dwarf mistletoe infection.
D. Male (staminate) flowers of dwarf mistletoe.
E. Dwarf mistletoe seed discharge.

Figure 52.--(Reproduced from Baranyay and Smith 1972, fig. 7; with permission.)

Spread is always greater in open than in dense stands where nearby foliage intercepts seed. The most rapid spread is from an overstory to the understory below. After logging, seed can spread from 30 to 50 ft (9-15 m) the 1st year seeds are produced. A single infected overstory tree disperses seed over an area of nearly 6,000 ft^2 (560 m^2) (Smith 1966). Thus, if trees are evenly distributed, less than 10 infected trees per acre (25/ha) could infect all intervening hemlock regeneration (Baranyay and Smith 1972). With early removal of the overstory seed source, about 86 evenly spaced, severely infected residual hemlock per acre (212/ha) would be required to produce a level of infection sufficiently high to cause significant early damage on all intervening hemlock regeneration (Smith 1977).

The lateral rate of spread through even-aged stands of hemlock is not known. Spread in even-aged pine has been estimated at generally less than 2 ft (0.6 m) per year; spread through open stands is about 1.5 times faster than through closed stands because mistletoe plants are more vigorous and seed travels farther (Hawksworth 1958).

Long distance spread of dwarf mistletoe is less common. It is usually attributed to birds who remove the sticky seed from their feathers while preening.

The upward advance (vertical intensification) of infection in the crown of a tree proceeds at the rate of about 2 ft (0.6 m) per year, the rate being more rapid in open than closed stands (Richardson and van der Kamp 1972).

There is the possibility that vigorous trees will outgrow dwarf mistletoe. Russell (1976) suggests that the vigor of dwarf mistletoe is correlated with the vigor of the host. Thinning, therefore, increases dwarf mistletoe growth; but it also stimulates tree growth, and the net effect is uncertain.

Dwarf mistletoe infection centers usually occur in a patchlike pattern related to the origin and development of the stand. They tend to be well defined, with narrow transition zones from infected to uninfected stands. Wildfire or broadcast burning of logging slash destroys most of the dwarf mistletoe seed source, and a new crop of hemlock seedlings can develop into an even-aged stand essentially free of the disease. On the other hand, young stands that become established prior to removal of an infected overstory may develop severe infections. The most severe infections seem to be in all-aged stands, where young trees are periodically showered with seeds from the overstory as they develop.

Few surveys of mistletoe infection have been made in coastal forests, and the nature and extent of infection is not well known. Shea (1966) reported that pockets of infection occur along the Columbia and Quinault Rivers on the Washington coast, and infection was more severe near the ocean. Greatest infection was in all-aged stands or those that had developed under an infected overstory. Similar results were obtained in the Waldport, Oregon, area of the Siuslaw National Forest. Infection was most intense along moist creek bottoms, presumably because past wildfire had skipped over wet areas, leaving infected trees as a mistletoe seed source.

Infected hemlock trees advance through stages of initial infection, brooming, stem swelling, development of spiked tops, and ultimate decline. Shea (1966) found that in 60- to 80-year-old well-stocked stands diameter increment did not suffer unless infections were severe and deforming. Smith (1964) classified trees by intensity of infection as light, medium, and heavy and for each class compared height growth during the decade 1950-60 with growth during 1920-30. Reduction in growth attributed to intensity of infection was 9, 19, and 57 percent, respectively.

Shea observed that severely infected trees were often overtopped by their neighbors. This was documented later by Smith (1968) who felled and sectioned lightly and severely infected trees that averaged 110 years old. The severely infected trees proved to be 39 years older, and in 1905 averaged 17 ft (5 m) taller than the lightly infected trees. By 1960 the lightly infected group was growing 90 percent faster in height and 34 percent faster in volume. When felled and sectioned in 1963, the lightly infected trees had surpassed the others, indicating the start of a selection process favoring lightly infected trees.

Growth losses in dense stands are reduced when adjacent mistletoe-free or lightly infected trees are available to replace those severely infected. Also under dense canopies, brooms often die or remain small. The net effect on growth in dense stands may be small and overshadowed by the competitive effects of severe overstocking. In open stands and along stand borders, dwarf mistletoe spreads faster, and trees are deformed earlier and more severely.

Englerth (1942) first documented that dwarf mistletoe infection leads to damage by other agents. He dissected 801 western hemlock trees, mostly on site 3 and 4 lands in western Oregon and Washington. He found that dwarf mistletoe burls and swollen limbs near the trunk had provided the entry courts for over 30 percent of the decay volume. The principal decay organisms gaining entrance this way were white mottled rot (*Fomes applanatus*), white trunk rot (*F. hartigii*), and white spongy rot (*Ganoderma oregonense*). Western hemlock trees weakened by dwarf mistletoe infection are more vulnerable to insect attack. For example, infected trees do not survive successive defoliations by the hemlock looper as well as dwarf mistletoe-free trees (Buckland and Marples 1952).

Dwarf mistletoe infections also affect wood properties. A beneficial effect is that reduced specific gravity and lower moisture content of infected wood improves floatability of hemlock logs. Most other effects are detrimental. Harvesting deformed trees with broomed limbs and spiked tops is dangerous. The hard, dense knots associated with broomed limbs dull saws and chippers. Variations in specific gravity in infected logs cause warping of lumber, and the lowered specific gravity suggests lower strength properties and pulp yield (Wellwood 1956).

Techniques For Control

The outlook for dwarf mistletoe control is good. It can be controlled silviculturally by cutting infected trees, thereby removing the seed source, or by establishing nonsusceptible species, such as Sitka spruce, Douglas-fir, or cedars.

The possibility of using biological agents for control of dwarf mistletoe has been investigated. Three species of fungi that restrict development of aerial shoots have been found; other fungi, birds, rodents, and insects are being studied (Hawksworth and Wiens 1972). Biological agents, however, have not yet proved successful for operational control (Russell 1976).

Considerable work has also been done on the development of chemical to control dwarf mistletoe, but no material has been found that warrants widespread application (Baranyay and Smith 1972).

A detection survey is the basic step in a control program, the objective being to determine occurrence, distribution, and intensity of infections and to identify areas where intensive surveys are needed. The survey often can be conducted concurrently with timber cruising, presale planning, or sale layout (Shea and Orr 1963, Graham 1967). Boundaries of infected areas often coincide fairly well with timber type boundaries, and to this extent aerial photos would be useful in mapping them.

Dwarf mistletoe infections occur in a patchwise and nonrandom pattern, and an operational survey is usually needed to delineate infection boundaries and to assemble facts for deciding for or against treatment and the best type of treatment. Information needed includes:

1. Age of stand and current cutting plans.

2. Species composition and suitability of site for species other than hemlock.

3. Intensity of infection in the understory, density of stocking, and crown characteristics.[18/]

4. Topography and available logging methods and their effects on the minimum area that can be treated economically.

5. Available residue disposal methods.

6. Restrictions due to recreation use, esthetic values, etc.

The second step in a control program is to select the best treatment for each stand condition. Two general approaches are available: removal of the seed source by cutting infected trees and substitution of a nonsusceptible species. Basic steps to be taken in the first approach include removal of all infected overstory, sanitation cuttings in the understory, and followup sanitation treatments as required. If severely infected, the entire understory should be destroyed. The second approach, substitution of a nonsusceptible species, can be done by seeding, planting, or favoring a nonsusceptible species in precommercial and commercial thinning. The following examples and discussion illustrate some conditions found, factors considered, and treatments applied.

[18/] The six-class rating system developed by Hawksworth (1977) (fig. 53) provides a method for describing intensity of infection. A modification of the system may prove desirable in dense hemlock stands (Smith 1969).

A condition often found in Alaska and British Columbia is infected old-growth hemlock in mixture with Sitka spruce, with an understory of almost pure hemlock of various sizes severely infected by a periodic barrage of mistletoe seed. The prescription is to clearcut the stand and destroy infected understory seedlings and saplings by logging. Infected saplings not destroyed during logging are cut later by a special crew. The objectives are to stop deterioration of the decadent old growth and eliminate the dwarf mistletoe seed source; then the new stand, whether established by natural regeneration, seeding, or planting, can develop free of infection.

Variation in tree height and density of stocking in a young stand are important factors determining response to dwarf mistletoe infection. Infected trees growing in the open or extending above the general canopy may develop vigorous infections, produce lots of mistletoe seed, and infect surrounding trees that may have escaped earlier infection.

Large variations in density of stocking and in tree height usually are found in the understory of mistletoe-infected, old-growth stands; so control action by clearcutting is usually indicated.

When a young stand has light infection or infection centers are widely distributed, sanitation cuttings are indicated. The objective is to remove as many infected trees as economically feasible, particularly those above the general canopy in a position to shower mistletoe seed on nearby trees.

Most sanitation cutting should be done in conjunction with juvenile spacing or early precommercial thinning operations. The optimum time seems to correspond well for both spacing and sanitation; that is, between a stand age of 10 and 20 years. Only healthy hemlock should be selected for crop trees. When hemlock crop trees are selected, the six-class rating system of Hawksworth (1977) may be a useful guide (fig. 53). For example, at stand age 20 the objective might be to leave no

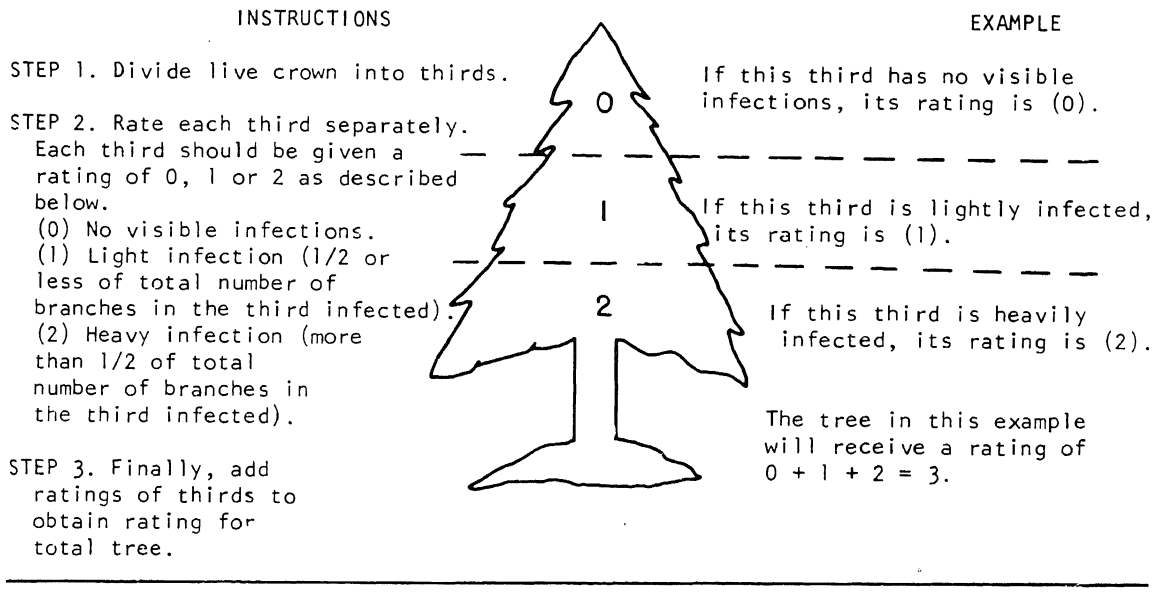


Figure 53.--The six-class mistletoe rating system (Hawksworth 1977).

hemlock trees with a rating of more than 2; at stand age 10 no hemlock with a rating of over 1. In this way the most heavily infected trees are removed; those left are not likely to sustain significant losses or can be removed in later intermediate cuttings if they have become more seriously infected.[19/] Additional selection can be on the basis of resistant species, such as Douglas-fir or Sitka spruce. If crop trees are selected on the basis of diameter, there will usually be a tendency to select these resistant species because their diameters are usually larger than hemlocks' at this age class.

Control by manipulation of species can be accomplished by clear-cutting and planting desired species. Seeding usually is not appropriate because hemlock may seed in naturally and dominate the site. Broadcast burning, if practiced in the area, will help destroy infected hemlock seedlings and clean up the area for more efficient planting.

In recreation and special use areas where it is desirable to maintain a forest canopy and timber production is not the major objective, control of dwarf mistletoe may not be warranted. In fact, the bizzare shapes of trees with severe stem infections and branch brooming may add to the esthetic appeal of some stands. In campgrounds and other heavily used areas, however, the heavy brooms may be hazardous. Current recommendations call for pruning of heavy, broomed branches in the interest of safety. Stem infections can also contribute to stem breakage during windstorms, and this factor should be considered in selection and maintenance of recreation areas.

Timber along cutting lines, if infected, can be a source of infection for adjacent reproduction for about 50 ft (15 m) from the line, depending on slope. This edge effect becomes more important as the size of the regenerated area decreases, because small areas have a proportionally larger perimeter. The edge effect can be minimized by locating cutting lines through mistletoe-free areas or by using clearings, rock outcrops, lakes, streams, roads, or meadows as cutting boundaries. Spread of infection can also be reduced by thinning infected trees from adjacent timber, by destroying hemlock and planting a resistant species in a 50-ft (15 m) strip around the edge of the regenerated area, or by cutting the adjacent stand while the hemlock reproduction is from 5 to 10 years of age or still small enough that only a few seedlings have had time to be infected.

Every stand is different, and the above examples illustrate some of the situations found. A separate control plan should be developed for each infected area. The general objective is to minimize losses in forest value commensurate with realistic costs of control.

Dwarf mistletoe control programs need not always compete with silvicultural treatments needed for other purposes, because in many cases they can be combined. Priority for control measures should be set on the basis of cost and feasibility of control and probable benefits. Often these will be prevention measures in newly regenerated stands; for example, removal of infected saplings during or after logging. Removal should not be delayed long as infection from residual trees increases with age of the stand (Stewart 1976). Felling or herbicide treatment costs are low, and future productivity of the new stand may be increased considerably. In an active mistletoe-control program, infected saplings should be cut during the logging operation, thereby avoiding a special trip over the area. Sanitation thinning in

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[19/] Personal communication, R. B. Smith, Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

connection with early spacing operations in young stands often comes next, followed by salvage of dwarf mistletoe-infected, mature or overmature trees.

The last step in a control program is to schedule followup treatments at approximately 5-year intervals after initial treatment. Infections missed earlier should be recognizable but should not have had time to disseminate much seed.

Hemlock dwarf mistletoe is a forest disease that can be truly controlled through silvicultural treatment, often at little additional cost. Successful control will require intensive management in the form of thorough planning, careful treatments, and systematic followup.

Detailed benefit-cost analyses for control of hemlock dwarf mistletoe are not possible at this time. Although it may be possible to determine growth reductions in individual trees, growth losses cannot be determined on a stand basis. Yield tables now in common usage cannot be used for bench-mark purposes because it cannot be known if sample trees were infected and if so, to what intensity.

Benefits of a control program in recreation and special use areas cannot be evaluated only in terms of growth losses but must be evaluated also in terms of safety and risk. Benefits may be analyzed from an actuarial or legal standpoint more effectively than from a strict economic standpoint.

Certainly, more information is needed on silvicultural control, reduction in stand yield, parasite-host relationships, and the possibilities of chemical, biological, and genetic control. Current control programs, however, should not be delayed for new information.

MINIMIZING WIND DAMAGE

Wind damage is common in the hemlock-spruce type. Each year storm winds take their toll in uprooted and broken trees, reduced growth rate from broken branches, and the shearing of twigs and leaves. Occasionally, storm winds cause spectacular losses. Five extensive blowdowns occurred:

Date of storm	Area covered	Volume of blowdown (Million fbm)	Reference
Jan. 9, 1880	Northern Oregon and southern Washington	--	Decker et al. 1962
Jan. 29, 1921	Olympic Peninsula	20/ 8,000	Decker et al. 1962
Dec. 4, 1951	Western Oregon	20/ 3,700	Ruth and Yoder 1953
Oct. 12, 1962	Western Oregon and western Washington	20/ 11,190	Orr 1963
Nov. 1968	Southeastern Alaska	5,000	21/

20/ Volumes shown include damage inland.
21/ Unpublished data on file, Region 10, Timber Management, Juneau, Alaska.

Scattered blowdown also occurs during years when there is no catastrophic storm and often goes unnoticed except by local land managers. This storm damage also adds up to large losses. In over-mature stands, trees may be weakened by root or stem rot or dwarf mistletoe infection and may blow down, even though the windstorm is not particularly severe.

Storm damage also may be classified as uprooting, stem breakage, crown damage, and root damage. Uprooting occurs mainly on poorly drained soils and stem breakage on well-drained soils. It is important to differentiate between these situations because trees growing on them need to be treated differently.

Wind damage to needles, twigs, and branches is less spectacular but is important. After a major storm the forest floor may be carpeted with a layer of this material. Productivity of the forest is slowed while the photosynthetic area is being replaced.

Root damage occurs when roots work up and down in the soil during wind sway; this too slows growth. Trees are less windfirm during the recovery period. Root damage also provides an entry court for disease organisms.

Sudden exposure of trees along blowdown edges also causes growth reductions. There is a slowing of height growth and sometimes dieback of tops. Spruce tends to put out epicormic branches along the stem, resulting in a lengthening of the crown and a lowering of the center of gravity of the tree.

Risk of wind damage varies widely, depending on exposure to storm winds. In severely exposed localities, forest management must be dictated largely by wind. The forest manager should recognize the risk and design the silvicultural systems to minimize wind damage. Barring catastrophe, the manager should be able to carry out harvest cuttings, regeneration, and stand management with little disruption--even though wind dictated the planning. On the other hand, the manager may design the silvicultural systems with little concern for the wind, only to have to alter plans time after time. The result will be mainly a salvage operation dictated by the wind.

Even when downed trees are salvaged, there is substantial financial loss. There is investment loss from premature harvest of the trees, broken trees with volume loss, and downgrade caused by insect attack and decay. Downed timber must be salvaged promptly because of rapid deterioration (Boyce 1929, Childs and Clark 1953, Shea and Johnson 1962). There may be damage to improvements such as roads, culverts, fences, and buildings. There may be premature replanting costs. Logging costs are higher, and hazards are increased. The logger has no choice in direction of fall and must often work slowly to insure safety. A catastrophic storm can disrupt markets through an oversupply of logs and consequent drop in price. The supply can exceed the local manufacturing capacity, and this will require that logs be transported out of the local area.

Details of wind behavior in coastal forests and recommendations for reducing wind losses follow.

The North Pacific Wind System

Most winter storms originate in the western Pacific and follow a course east and northeast across the North Pacific to the west coast of North America. These cyclonic storms rotate counterclockwise around a central area of low barometric pressure. The prevailing storm tracks, as well as areas of maximum occurrence and genesis, are generally farthest south in February, farthest north in August, and farther south in spring than in fall (fig. 54) (Klein 1957). The normal storm track along the Aleutian Chain, the Alaska Peninsula, and the Gulf of Alaska exposes these areas to a majority of the storms crossing the North Pacific (Searby 1968). On an overall basis, the Gulf of Alaska leads the northern hemisphere every month from October through May in cyclonic frequency (Klein 1957).

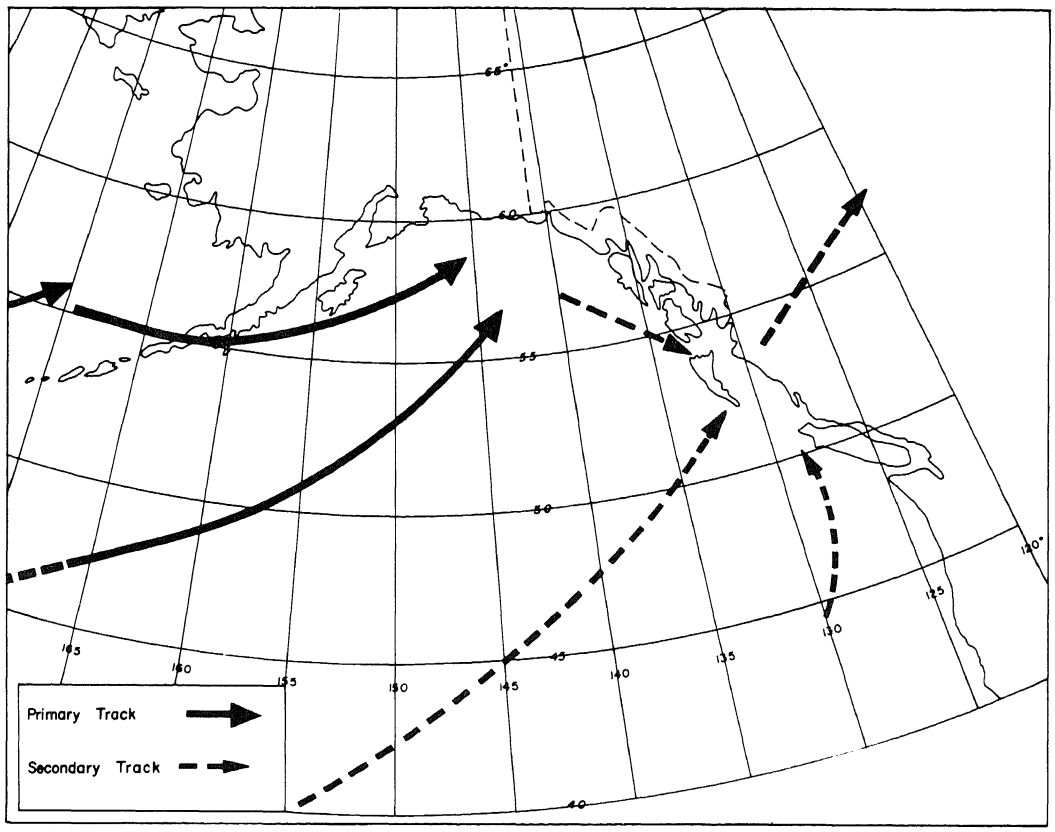

Figure 54.--Principal tracks of low-pressure areas across the North Pacific Ocean for November (Klein 1957).

In Oregon and Washington, the highest velocity and greatest damage has been from south and southwest winds of an approaching storm. Gale-force winds approach the shoreline with increasing frequency in October and November, reach a peak in December and January, then decrease in February and March (U.S. Navy Hydrographic Office 1961).

In southeast Alaska, the strongest and most damaging winds are from the southeast; they occur in the fall, particularly during September, October, and November (Searby 1968). The storms that produce these winds frequently begin as wave developments on cold fronts or occlusions that have passed east of the coastal range and trail into the gulf near the stationary weather ship located at 50°N, 145°W. The wave develops to the east or southeast of this and remains rather weak and fast-moving until it approaches the coast in the vicinity of the Queen Charlotte Islands. At this stage, it deepens rapidly and moves north-northeastward at 40 to 50 mi/h (64 to 80 km/h), often accompanied by winds of gale force. Most often the time interval, from the time the wave is detected until it has moved through the entire Alaska panhandle, is only 24 to 30 hours. This type of storm produces wind gusts that at times exceed 100 mi/h (160 km/h) in southeast Alaska and 80 mi/h (130 km/h) in the northern sections.[22/]

Two examples of damaging gales are the Columbus Day storm of October 12, 1962, which battered Oregon and Washington forests, and the Thanksgiving Day storm of November 28, 1968, which raked southeast Alaska.

The Columbus Day storm of 1962 (Decker et al. 1962, Lynott and Cramer 1966, Orr 1963) followed a variable path across the Pacific, finally reaching a deep low of 960 mbar near latitude 40°N and longitude 130°W off the coast of northern California about 10 a.m. P.s.t. This was far southeastward from the usual location of deep lows. The Columbus Day low then followed a northward course just off the coast and reached the mainland at Tatoosh Island, Washington, some 12 hours later. Most anemometers were destroyed by the wind, but windspeeds, based on geostrophic winds as indicated by differences in barometric pressure, were estimated by Lynott and Cramer (1966). Maximum 1-min velocities of surface winds estimated as 50 percent of geostrophic winds were 100 knots/h (185 km/h) in Oregon and Washington coastal areas. Orr (1963) reported maximum gusts at 117 knots/h (217 km/h). General wind direction was southerly. The storm winds traveled northward along the coast with no major mountain ranges in their path. The intensity of the low did not subside until the storm angled inland in northern Washington and British Columbia.

The severe storm that produced extensive damage throughout southeast Alaska on Thanksgiving Day of 1968 was an especially severe example of a fall gale. As the storm approached the Alaska panhandle, the pressure fell rapidly at Annette Island for a prolonged period of time, reaching a low of 736 mbar. Once the frontal system passed Annette Island, barometric pressure there began rising rapidly while the pressure at Sitka and Juneau continued to fall rapidly. A low pressure of 725 mbar was recorded at Juneau prior to frontal passage. The Thanksgiving storm produced windspeeds to 50 mi/h (80 km/h, with

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[22/] Personal communication from Lief Lie, Weather Service Forecast Office, NOAA, Juneau, Alaska.

usts as strong as 90 mi/h (145 km/h) in the Ketchikan area and gusts o 78 mi/h (126 km/h) in Juneau (see footnote 22).

ora Winds

During the winter months, cold, dry winds occur in many places long the Pacific coast. These fall or bora winds develop where steep ountain ranges parallel the coast, producing sharp climatic differences etween the cold interior and warmer coastal areas. Winds of this ype are common in coastal mountainous areas throughout the world nd are usually known by local names. In Europe the bora (derived rom the Greek boreas, "north wind") which occurs along the coast of almatia on the Adriatic Sea is the best-known example and serves to dentify the type. Examples from southeast Alaska are the Taku winds n the Juneau area and the Stikine wind in the Wrangell area (both amed for local river valleys). Farther south, the strong winds that ccasionally blow out of the Columbia River Gorge are well-known xamples (Willett and Sanders 1959).

For a bora to develop a strong pressure gradient must exist etween the interior and the coast. This difference can develop ither as the result of an arctic high-pressure area over the interior r as a deep low-pressure area along the coast. Cold, continental air s forced through river valleys. This falling air adds velocity to ind influenced by the pressure gradient. The falling, cold air gains ome heat adiabatically, but this does little to offset the initial xtreme temperature difference, and the wind reaching the coast is old relative to normal coastal air.[23/]

In southeast Alaska, perhaps the best known bora-type wind is the aku. Taku winds blow predominantly from the northeast and occur lmost exclusively during the winter months. They are extremely urbulent, and gusts reach hurricane force.

In the Juneau area, local, extremely gusty winds may also result rom downslope movement of cold air from the nearby elevated icefield. uring clear weather, radiative cooling produces a shallow layer of xtremely cold air over the icefield which may spill over the seaward ountain slopes in the form of katabatic winds. Such local winds ften occur during taku conditions. It should be noted, however, that t is the deep breakthrough of cold arctic air from the Yukon and acKenzie Basins in northwestern Canada rather than the shallow, old, surface air over the icefield that favors development of the aku (see footnote 23).

Considerable damage to property may occur from taku winds, and ney pose great hazard to boats and aircraft. In the localized areas here they occur frequently, vegetation tends to adapt to these winds ver time so that sudden damage to forest stands is rare. Annual amage to stem and branch tips results in abnormal growth habits of rees; trees tend to be short and highly tapered, with heavy root evelopment, and crowns develop primarily on the leeward side of rees. Trees offer mutual protection, and stands tend to be of uniform eight, with little opportunity for individual trees to extend higher

[23/] Gordon D. Kilday. Taku winds at Juneau, Alaska. Undated report on file, eather Service Forecast Office, NOAA, Juneau, Alaska.

than the general level of the stand. In extremely exposed positions, trees may be gnarled or prostrate. Reproduction may be impossible in extremely exposed positions, and timberline is held at lower elevations than on less exposed slopes nearby.

Thunderstorms

There are other types of winds strong enough to uproot trees, and they may account for the fairly rare blowdown that does not conform to the pattern established by general airflow. Although hemlock-spruce forests are not in an area of general thunderstorm activity, thunderstorms do occur, usually along the squall line preceding an advancing cold front. Strong downdrafts may develop during the later stages of a thunderstorm, hit the forest canopy or the ground with considerable force, then spread out laterally in the direction of least resistance. Velocities may reach 100 mi/h (160 km/h). Thunderstorm activity decreases northward along the coast, and in southeast Alaska thunderstorms are extremely rare.

Tornadoes

Tornadoes are rare in the Pacific Northwest but may occasionally damage forests and property. During the 1960's, three tornadoes occurred in the Puget Sound area of Washington (Feris 1970), and one struck the area of Portland, Oregon, and Vancouver, Washington, on April 5, 1972 (Porter 1973). Such "twisters" may destroy forests along a narrow track for several miles but do not cause widespread damage.

Wind Behavior Over the Forest

The general direction of storm winds is well known in most localities or can be determined with little difficulty--for the forester, the best evidence is the orientation of windthrown timber. In many areas, historical records of wind direction and velocity also are available. Wind direction of a particular storm is common knowledge to local weather observers, most pilots, and fishermen. A problem for the forester is to determine whether all storm winds come from approximately the same direction. Except for bora winds, the strongest winds in the hemlock-spruce type generally come from the southeast to southwest. The fact that they come from this 90° quadrant greatly simplifies the job of developing cutting programs to minimize damage.

Wind behavior over the forest is a complex phenomenon influenced by the direction of airflow and its velocity, the relief of the land, and the surface of the vegetation. Maintaining a smooth surface of forest canopy minimizes the amount of energy that can be transmitted to the trees and confines it to the tips of the trees (Fraser 1965). A rough surface, as in old-growth stands, causes more turbulent airflow; and much greater wind forces may be imposed on the exposed tree crowns. The rougher the surface the greater the reduction in airflow at the surface and the greater the turbulence in the downwind area.

Topographic Effects

The direction and velocity of the airflow may be changed by opography, and the forester should know where and to what extent this ccurs in an area. On windward slopes, changes in direction probably re less in the horizontal than in the vertical, with the airflow ending to go up and over a ridge rather than veer much to the right r left. The maximum directional change generally does not exceed 90°, s when winds flowing directly toward a vertical cliff veer upward, ght or left. Apparently, they do not change direction enough to ave an appreciable vector back toward the general airflow. The trong, continuing airflow itself seems to prevent this.

Velocity and turbulence of winds hitting a mountain ridge depend the elevation of the mountain, steepness of slope, angle from which he winds come, and the general topography of the area (Hutte 1968). hen winds strike a ridge at right angles, the airflow is forced ward, causing vertical convergence of streamlines and increased elocity in the vicinity of the top. East-west ridges between coastal treams and southerly storm winds make this perpendicular approach a ommon one in the Oregon-Washington portion of the hemlock-spruce one. Resulting wind damage often starts on the crest of the ridge d extends some distance down the lee slope (fig. 55) (Ruth and oder 1953). Heavy wind damage on ridges and upper lee slopes has een reported by several authors[24/] (Alexander 1964, Gratkowski 1956).

Figure 55.--Severe storm damage on the Siuslaw National Forest, Oregon. The wind blew up the main drainage from right to left. Damage is most severe on the lee slopes of secondary ridges.

24/ Pegues, J. J. 1959. The effects of windthrow on forest management on ree farm license number seven. Unpublished thesis submitted to Board of Examiners, ssociation of British Columbia Foresters, Vancouver, B.C. 68 p. plus map.

Concentration of damage on gentle lee slopes apparently is due to a lee-wave phenomenon, documented by studies in Britain (Gloyne 1968, Aanensen 1965). An airflow with suitable velocity and vertical temperature gradient across a series of properly spaced ridges will develop sympathetic undulations, with strong surface winds induced to blow down lee slopes. Thus, strong winds may adhere closely to lee slopes, whereas only gentle winds may be apparent on windward slopes. Lee flow was common during the December 4, 1951, storm in the Oregon Coast Ranges, and most damage occurred on lee slopes. If slopes were over 70 percent, however, winds apparently did not adhere to them and there was little damage (Ruth and Yoder 1953).

A contrasting result occurred when the January 1968 wind damaged Scottish forests, many of which were Sitka spruce plantations. The wind usually did not adhere to lee slopes over 10°, and only 7 percent of the damage was on lee slopes. Forty-five percent occurred on windward slopes or slopes oblique to the wind. Thirty-two percent was associated with funnels and ridgetops (Neustein 1971).

Wind patterns are generally more turbulent and erratic on lee slopes, but here too direction of fall in hemlock-spruce forests does not indicate wide variations in wind direction during storms. Most uprooted trees have their tops pointed downwind, in line with the general airflow. When winds flow over a bluff, the lee side is protected from the direct force of the storm. The air below the rim may start to rotate and form a large, stationary roll eddy, with surface winds below the bluff actually blowing upslope opposite to the airflow over the rim (Buck 1964). Such upslope winds apparently do not cause blowdown in hemlock-spruce forests. Timber in the lee of bluffs and very steep slopes generally is considered well enough protected from storm winds that it may be managed without serious risk of wind damage.

When winds flow parallel to a ridge, velocity and turbulence are greatest in the lower slopes. If the wind crosses a ridge obliquely, often there is turbulence near midslope and a channeling of wind direction along the slope (Hutte 1968). This is common in southeast Alaska and parts of British Columbia where storm winds tend to funnel up straits, inlets, and main canyons.

If a mountain protrudes above the general terrain, the airflow will pass around it as well as over the top and there will be an acceleration of windspeed on the shoulders. With a south wind, for example, windspeed will increase on the east and west slopes. There also may be increased velocity in the leeward area of the mountain, particularly if the topography is rising again in that area (Hutte 1968). A similar acceleration of windspeed occurs when wind flows around the nose of a ridge.

The 1951 storm along the Oregon coast caused considerable wind damage on the tops of small ridges in the lee of a higher ridge and on flats in the lee of a long, steep slope (Ruth and Yoder 1953). This latter phenomenon has also been noted in southeastern Alaska where the topography often rises steeply from the shoreline and then levels off to a gentle slope or flat. Trees on steep slopes often remain intact, with most wind damage occurring on the flats to leeward. An added factor here is that the water table may be higher on flat areas, thereby limiting rooting depth.

Heavy storm damage may occur in and downwind from gaps and saddles in main ridges. Funneling of wind through such openings requires both vertical and lateral constriction of the airflow, with resultant increases in velocity (Alexander 1964, Buck 1964).

According to Brooks (1949), large vortexes (mountain tornadoes) may form in the lee of bluffs and steep slopes and develop wind rotational velocities over 100 mi/h (160 km/h). Apparently they are caused by friction of storm winds on mountain peaks and ridges. The circular pattern could cause trees to blow down in any direction.

Gentle, convective winds--such as land and sea breezes and valley and slope winds--and their interactions do not cause blowdown and have been disregarded in this discussion.

The Stand Border

Clearcutting a stand of tall trees in effect lowers the relief of the land and, at the same time, leaves a vertical but somewhat permeable wall around the perimeter of the opening. Depending on the size of the clearcut opening, the wind may dip down into it enough that some of the border is exposed to the full force of storm winds. Wind velocity in the center of an opening 50-tree heights across reaches 95 percent of velocity in the open (Flemming 1969). The airflow strikes border trees and is forced either over the forest canopy and, to some extent, under and through it, or it blows down the trees. If the trees remain standing, the greatest restriction to airflow is the foliage at canopy level. The flow is somewhat greater below the live canopy and above the understory vegetation than within the canopy itself (Bergen 1971, Raynor 1971). Most of the airflow, however, is forced abruptly upward. This flow tends to dip back down in a wavelike motion and may damage the interior of the stand downwind from the stand border. Some airflow is deflected right or left along the border.

Stability

The first row of trees along a recently exposed stand border bears the brunt of storm winds. Tree stability depends, in part, on how much exposure was actually increased by the harvest cutting. An old-growth tree that has its crown above the general level of the forest canopy is well exposed to storm winds in the uncut stand. The increase in exposure may be limited to increased wind pressure on the lower bole, and its chances of survival are quite good. On the other hand, a young-growth tree that has its crown below the general level of the canopy is well protected from storm winds by its neighbors. Full exposure leaves only limited chance for the tree's survival.

Orientation

Storm winds blowing over the forest canopy dip down into clearcut openings, and most storm damage occurs on the lee or downwind side of the opening. This is illustrated by observations on the Cascade Head Experimental Forest after the storm of December 4, 1951. Winds were from south 30°W. Ninety-three percent of the storm damage occurred

along the north and east boundaries of eight clearcuts compared with only 7 percent along the south and west boundaries.

Cutting boundary	Number of damaged trees	Percent of volume
North	461	44
East	568	49
South	29	3
West	63	4

In general, it appeared that if the northeast cutting boundary was on a windward slope, there was less blowdown than if it was on a leeward slope (Ruth and Yoder 1953). A similar pattern was observed on 55 clearcuts in the Oregon Coast Ranges and has been reported in other timber types (Alexander 1964, Boe 1966, Neustein 1965; also see footnote 24, page 133).

Length

Small clearcuts, per acre harvested, suffer more wind damage than large clearcuts. Two main factors are at work. One is the consistent reduction in airflow as an opening becomes smaller. For example, the airflow at midcrown level at the center of a 1-acre (0.4-ha) clearing is 40 percent of that in a 10-acre (4-ha) clearing. The other factor is that small openings, per acre harvested, have more perimeter than large ones. For example, a square 40-acre (16-ha) clearcut has 1 mile (1.6 km) of cutting boundary. The same acreage harvested as 80 half-acre (0.2 ha) clearcuts has 9 miles (14 km) of cutting line exposed to wind damage. The effects of longer cutting boundaries associated with small clearcuts generally outweigh the reduction of wind velocity (Neustein 1965, Neustein et al. 1968). Therefore, clearcutting many small areas rather than a few large ones is likely to increase wind damage. Also, small clearcuts allow less flexibility in selection of locations for windfirm cutting boundaries. On the other hand, openings may be made so small that the wind does not dip down into them enough to cause damage. In hemlock-spruce forests these openings would probably be classed as thinning or group selection cuttings rather than clearcuttings.

Channeling Effects

Acting as a wind barrier the stand border may funnel the wind, much as the walls of a narrow valley would. If the wind is funneled into a narrow pocket or vee, the velocity is increased and damage may occur at the apex (Alexander 1964, Gratkowski 1956, Curtis 1943).

A road right-of-way also may lead to storm damage. If a straight section of the road parallels storm winds, the wind may funnel along the right-of-way with increased velocity and cause damage where the road turns. Examples of wind damage along straight roads connecting nearby clearcuts are common.

Winds that blow across rather than along rights-of-way may also cause damage. Munger (1946) observed damage along an east-west ridgetop road in coastal Oregon where winds were from the south to southeast.

found 5.8 times more trees uprooted or broken within 100 ft (30 m) the right-of-way than within 100 to 200 ft (30 to 60 m). This 30- 100-ft (9- to 30-m) wide opening significantly increased wind mage. Inspection of rights-of-way in a forest stand can be a guide local wind hazard.

e Windfirm Stand Border

Most natural hemlock-spruce stands have a windfirm stand border at develops with the stand and protects it from wind damage (fig. 56). ese borders are readily seen along waterways and around meadows or skegs. They are roughly wedge-shaped and are best developed where eir leading edge points into storm winds. At the perimeter, they gin with native ground vegetation. This provides wind protection r establishment of shrubs which then grow taller and provide protection r tree seedlings. These usually are Sitka spruce or lodgepole pine ich may develop into gnarled, windswept specimens. Back into the and, the trees grow progressively taller, each tree protected by ees to windward. The timber stand soon reaches maximum height for the site, after which environmental factors other than wind limit growth. The wedge-shaped stand border lifts storm winds up and over the timber stand and generally is quite effective in protecting it from wind damage. Also, there is less tendency for the wind to dip down into the interior of the stand than when the stand border is vertical. If the trees along the leading edge are felled, the next high wind can be expected to damage exposed trees, which have not become adapted to wind stresses (Whitehead 1968).

gure 56.--A windfirm stand border facing the beach at Yakutat, Alaska. Nearly all trees in this border are Sitka spruce.

Wind Resistance of Trees

Windfirmness of a forest tree is determined mainly by the force of the wind on the crown versus the inertia of the soil mass gripped by the root system. When a storm is of only moderate intensity and duration, almost all the trees that uproot will be those with poor anchorage. Trees with deep sinker roots generally resist the wind and remain standing. They are, however, susceptible to uprooting or stem breakage if the wind is strong enough. The forces of

the wind may be approximated by the percentage of broken trees. If a high percentage are broken, the wind was an unusual one of truly hurricane force. If most trees were uprooted, probably the wind was less severe.

In general, trees become less wind resistant as they grow taller (Andersen 1954). The turning moment at the base of the tree increases with the length of the lever arm, top weight generally increases relative to root weight, a larger crown has more wind resistance, and a heavier crown leaning in wind puts more tension on the root system. These and other factors account for generally more storm damage with increasing tree height.

Winds impose bending stresses on the roots and boles of trees and thus stimulate growth conducive to windfirmness (Andersen 1954). Accelerated growth occurs on the lee side of conifers (Laitakari 1929, Bannan and Bindra 1970, Busby 1965). Many hemlock and spruce examined in exposed situations on the Oregon coast showed large, strong, supporting roots on the lee side; and stumps had accelerated radial growth on that side of the main stem (figs. 57 and 58). In contrast, Fraser and Gardiner (1967) did not find this tendency in young Sitka spruce plantations in Great Britain.

Figure 57.--A dominant Sitka spruce tree on a ridge exposed to southerly winds. The north side of the tree is buttressed at the base on the leeward (north) side. Cascade Head Experimental Forest, Oregon.

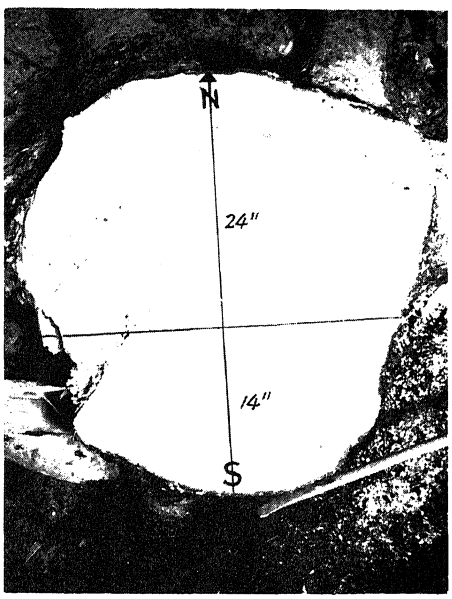

Figure 58.--Looking down on the stump of the tree shown in figure 57. The stump shows increased radial growth on the lee (north) side. Cascade Head Experimental Forest, Oregon.

Open-grown trees tend to be short and have rapid taper and large, low crowns. On the other hand, trees growing in the interior of a stand receive little stimuli from the wind and do not develop much windfirmness. They are especially vulnerable to damage when exposed along a cutting line.

Dominant trees growing in deep, well-drained soil tend to be more windfirm than trees in other crown classes. Their crowns reach above the general level of the forest canopy where they receive stimuli from prevailing winds. The deep soil permits development of strong root systems.

Tree pulling experiments by Fraser and Gardiner (1967) on plantation-grown Sitka spruce in Britain showed no measurable difference in resistance to overthrow between trees pulled upslope and trees pulled downslope.

Bending of tree boles during storms may cause structural weakness and more susceptibility to breakage during subsequent storms. Breakage of 30-year-old Sitka spruce in Britain occurred at bulges on one side of the stems. Investigation revealed the bulges to be fast-grown compression wood overlying a natural compression failure and associated ring shake. The bulges were attributed to bending during severe storms 2 years earlier (Forest Products Research Board 1964).

Soil Effects

Poor anchorage of trees generally results from shallow rooting. This may be due to shallow soil underlain by bedrock, an impermeable layer near the soil surface, or a high water table--the latter being most common in hemlock-spruce forests. It is not known what amount of excess soil moisture damages the roots or its duration, but it is clear that prolonged saturation will restrict rooting to the soil above the saturated layer. Under severe conditions, rooting will be restricted to the familiar flat plates seen on uprooted trees (fig. 59) (Fraser and Gardiner 1967).

Figure 59.--Uprooted western hemlock showing typical flat, platy rooting structure when grown on poorly drained soil.

Surveys in Sitka spruce forests in Britain have established a direct relationship between rooting depth and windfirmness which has been confirmed by tree-pulling investigations (Pyatt 1966). General observations and surveys indicate that the same relationships hold true in North American hemlock-spruce forests (Ruth and Yoder 1953).

There are significant differences in tree stability, depending on soil texture. Under moist conditions, trees growing in sandy soil are more difficult to pull over than trees growing in loam. Trees in loam soil are more stable than those in clay soil (Busby 1965, Fraser 1962, Fraser and Gardiner 1967, Pyatt 1966). The shear strength of most soils is reduced as moisture content increases; clay soils particularly lose strength when waterlogged (Busby 1965). Coarse-textured soils with large pore spaces, free drainage, and no compacted horizons are favorable for deep rooting.

Heavy precipitation or rapid snowmelt will saturate the soil whenever the rate of water entering the soil exceeds the infiltration rate into the subsoil. The most critical situation seems to be where an already high water table is raised still higher by heavy precipitation. Water makes the soil more pliable and less shear resistant and thereby reduces the stability of tree root systems.

Soils having a high water table often can be recognized by plant indicators. Skunk cabbage is a reliable one (Minore 1969b). Other species, such as western water hemlock, water parsley, and western golden saxifrage may also be used.

Storm winds often occur along with heavy precipitation, exerting maximum pressure on tree crowns when the soil is saturated. Single gusts may be strong enough to uproot trees, but often it is the combination of windspeed and duration of the storm that causes damage. The process is described by Hutte (1968) for Norway spruce in Germany. In wet, poorly drained soils, the main roots extend laterally, and vertical roots are absent or extend only a short distance into the subsoil. As trees sway in the wind, the windward roots may be lifted enough to separate from the mineral soil; each tree then depends on leeward roots to hold it upright. If leeward roots are thin, the tree uproots as soon as windward roots are separated from the soil. If leeward roots are strong, movement is transferred to the root plate which rises and sinks with strong gusts. As it rises, water runs into the cavity vacated by the roots. As it sinks, water and soil particles bubble out from under the plate on the windward side. The water tends to filter back under the plate but the soil tends to be deposited in a ring around its windward perimeter. Part of this soil comes from the windward part of the plate, but the greater part from the lee side where leeward prop roots are pushed deeper and deeper into water-lubricated soil. These leeward roots finally break, usually 4 to 8 ft (1.2 to 2.4 m) from the main stem as the tree is overthrown by a strong gust. Thus, when rooting is shallow, it is not only the wind velocity but the duration of the storm that determines wind damage.

The process is different on deep soils. A root plate generally is absent, and the root-soil mass scarcely moves during windsway. Most movement is limited to bending of the main stem. Unlike the situation where tree roots are shallow, the duration of the storm has little effect. If gusts are strong enough, stem breakage rather than uprooting will occur. Most situations are intermediate--wind damage is a combination of uprooting and stem breakage.

Topographic drainage is an important factor. When forest soils ave at least moderate slope, water tends to flow downhill and away. he ground water table usually remains well within the soil; or if t rises, it recedes rapidly, doing little damage to the root system. n level ground and gentle slopes, water drains away more slowly, amage to the root system is greater, and trees are less stable. uring storms or rapid snowmelt, the water-saturated soils become emiliquid and an insecure anchor for trees (Day 1950).

Freezing of soil is also a stabilizing factor in the northern ortion of the hemlock-spruce forests. In the mild climate of Oregon nd Washington, there is little soil freezing and trees are rarely tabilized by their roots being cemented in a mass of frozen soil. In laska gale-force winds are most common from September to December hen soils under forest stands are usually unfrozen; however, gales ometimes occur during the winter when soil is frozen. Patric (1967) eported that soil was frozen to a depth of 15 in (38 cm) during inter under a forest stand near sea level in the Juneau area. When oots are stabilized by frozen soil during strong gales, stem breakage ay occur more commonly than uprooting.

Decay

Diseases may destroy part of the root system of a tree and thereby ecrease its resistance to windthrow. Some hemlock-spruce sites have fluctuating water table within the rooting zone. It recedes during he growing season, allowing small roots to penetrate deeper into the oil. When the water table rises around these roots during the winter, hey often die from lack of aeration. The same process may occur over longer term, with roots penetrating into deep soil during dry years, nly to die back during an ensuing wet period. This recurring root ortality provides a continuous entry court for disease; and, according o experience with Sitka spruce in Britain, disease is more prevalent n areas having a high water table. A bunchy development of roots at he top of the impeded zone was reported by Day (1953) as evidence of oot dieback in Sitka spruce.

Mortality of many individual trees that uproot or break off in he uncut stand or along a stand border may be attributed to wind amage, with decay often the primary cause. Ruth and Yoder (1953) ound decay to be associated with at least 15 percent of the wind amage in hemlock-spruce in western Oregon. Even greater percentages ave been reported in other timber types (Gratkowski 1956, Alexander 964, Wiley 1965).

Hemlock and spruce may be damaged as trees sway in the wind and he roots rub against rocks in the soil. This is a common occurrence n windy areas where trees have restricted roots. The root plate aises and lowers during windsway, and underlying rocks abrade the roots. inker roots are particularly vulnerable. They move endwise and may e pushed directly into rocks where they develop frayed ends (fig. 60). imilar root damage has been noted by Day (1950) on Sitka spruce in ritain. Such root damage provides a ready entry court for disease rganisms. Damage tends to be less when trees are deeply rooted. The arge soil mass gripped by the roots tends to limit windsway to bending f the main stem, and there is less movement of roots within the soil.

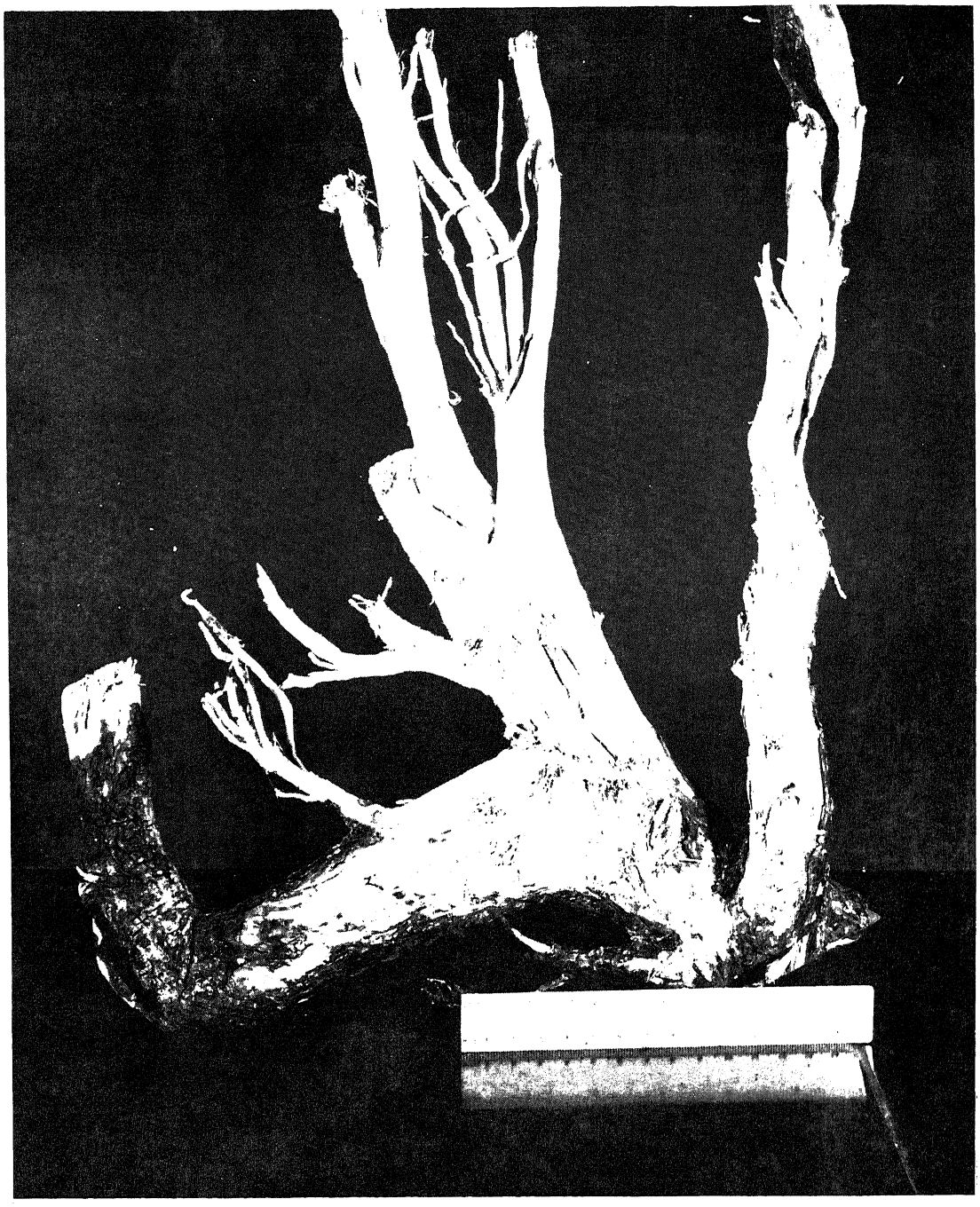

Figure 60.--Abrasion and frayed ends of sinker roots of Sitka spruce produced by movement against rock during windsway.

Stems broken by the wind and fresh-cut stumps left from salvage of blowdown provide entry courts for disease. For example, viable spores of *Fomes annosus* were found following the 1968 blowdown in Scottish forests, and stumps were treated with sodium nitrite to prevent infection (Burdekin 1971).

Exposure

There is a close correlation between general exposure of trees to storm winds and their windfirmness (Andersen 1954). Trees in an exposed stand border tend to be shorter and have more taper and stronger root systems than trees in the interior of a stand. Even though more exposed, they may survive a strong gale while the interior of the stand suffers severely (fig. 61).

Figure 61.--Many exposed trees along this beach fringe survived a strong gale while trees behind them were blown down. Zarembo Island, Alaska.

Exposed trees do suffer damage. Trees that grow in exposed locations develop great stability if soil conditions permit; but they too may have restricted rooting depth, suffer from root rot, or have other deformities. A major hazard exists when trees are exposed by harvest cutting or other events and gale-force winds occur before they increase in windfirmness.

Species Differences

There appear to be basic differences in wind resistance among the species. Western redcedar often is reported as most windfirm, followed by Douglas-fir, Sitka spruce, western hemlock, and Pacific silver fir (Boyce 1929, Gratkowski 1956). In many cases, however, observed

differences result from site preferences. Douglas-fir prefers well-drained sites which generally permit deep rooting. Hemlock and spruce, on the other hand, are often in the wetter areas where the water table restricts rooting depth. For similar soil conditions, Eis (1974) found root systems of western hemlock, Douglas-fir, and western redcedar to be very similar. Apparently much of the difference in tree stability noted in the field is due to site conditions.

Stands of red alder with an occasional hemlock or spruce extending above the alder canopy appear to be very windfirm, and little storm damage has been noted (Ruth and Yoder 1953). Plantations of spruce and Scots pine or lodgepole pine have been established in Wales, but apparently they are no more stable than pure Sitka spruce which is widely used as the most suitable tree in windswept areas. Sitka spruce has been planted widely except on dry knolls, areas where *Fomes annosus* is prevalent, and areas in east Wales where rainfall is less than 40 in (100 cm) per year (Stumbles 1968).

Stand Density Effects

Isolated and widely spaced trees often survive the worst of storms, yet thinning to increase tree spacing often leads to severe storm damage. Some authors favor no thinning in windswept areas (Stumbles 1968, James and Dier 1968); others report that thinnings will improve windfirmness (Alexander 1964, Fraser and Gardiner 1967, Crawford 1968, Stroempl 1971). Soil conditions, thinning intensity, type of thinning, and time usually are the key factors.

On well-drained soil permitting good depth for roots, thinning is believed to increase tree diameter and root growth and to cause trees to become more windfirm. Where rooting depth is restricted, thinning apparently encourages lateral extension of the root system but not vertical extension. This was the case on gley, peaty gley, and deep peat soils studied in Britain. In fact, rooting depth in thinned stands on such soils may be less than in unthinned stands (Fraser and Gardiner, 1967, Pyatt 1966). Fraser and Henman (1966) pulled over trees in lightly and heavily thinned plots and found the root systems after heavy thinnings to be significantly wider but shallower. Thinning did not improve a tree's resistance to being pulled over.

Thinning intensity governs the degree of exposure of trees left standing. An isolated tree fully exposed to the wind is stimulated to develop a strong root system. The crowded tree, on the other hand, depends on its neighbors for much of its protection. It struggles upward for light and develops a high root-top ratio. Removing its neighbors increases its exposure to storm winds, the degree of exposure depending on thinning intensity.

Type of thinning has important effects on subsequent stand stability. Thinning from below by removing mostly suppressed and intermediate trees does little to increase wind exposure of remaining crop trees. On the other hand, thinning from above exposes trees in the lower canopy which previously were protected from storm winds. Two Sitka spruce stands were thinned in Great Britain by removing 30 percent of the standing basal area, in the first by cutting dominant and codominant trees and in the second by removing only small-crowned trees from the

ower canopy. Unthinned plots provided a third treatment. Subsequent lowdown was greatest in the stand thinned from above and least in the nthinned plots, indicating that thinning from above is undesirable in indthrow-susceptible areas (Low and Taylor 1967).

Time is the other key factor. Thinning suddenly exposes trees of he residual stand, and growth of their roots and main stems are timulated. But this takes time, and many years will pass before heir stability approaches that of a long-isolated tree. Therefore, rees left after thinning initially are more vulnerable to wind damage han had there been no thinning.

Predicting Wind Damage

The probability of wind damage in a particular forest area can be stimated by observing tree anchorage, frequency and intensity of torm winds, tree height, exposure to storm winds, and local history f blowdown. Predictions may then be made of the height to which a tand may safely be grown before wind damage will make it impractical o carry it farther.

The recent blowdown history of a forest area may be observed and sed as an indicator of blowdown to be expected in the future. Obser- ations are easiest to make prior to salvage; but the uproots remain or observations later, if necessary. It is even possible to get a eneral idea of frequency of wind damage by observing the various tages of decay of windthrown trees or uproots.

The direction of fall indicates the direction of storm winds. ome trees are knocked down by others and may not fall directly down- ind. Gratkowski (1956) estimated that in one storm about one-fifth f the trees were knocked down, the percentage of understory trees reater than the dominants. General direction of fall is easily bserved from an airplane, from a vantage point, or from aerial hotographs.

The portions of an area most susceptible to blowdown may be dentified by above-average frequency of blowdown. Absence of recent lowdown, on the other hand, is only partial assurance that storm amage is not a problem. The stand may be vulnerable to damage, ut recent storms may have bypassed the area. Unusual storms may ring high wind velocities to previously sheltered areas.

Long-term blowdown history probably is the best measure of blow- own hazard. This can be estimated from the mound-and-pit microrelief f an area. When a tree uproots in the wind, the mass of soil material ntermingled with the root system generally is moved upward and laterally oward the direction of fall, leaving a pit which may be 2 to 3 ft 0.6 to 1 m) deep and several feet in diameter. As the tree roots ecay, the displaced soil material is deposited in a mound generally n the leeward side of the pit (fig. 62). If there is no history of ind damage in an area, wind may be disregarded in management planning.

Shallow rooting being a major factor in wind damage, an important art of predicting blowdown hazard is to obtain detailed knowledge of ooting depth. A soil survey with special attention given to rooting

Figure 62.--Mound-and-pit topography. Depressions in the ground and the adjoining mounds indicate windthrow of trees which have since disappeared; 100-year-old Sitka spruce stand, Cascade Head Experimental Forest, Oregon.

depth will be very helpful in planning harvesting operations. Generally, soil surveys are not detailed enough to locate small groups of shallow-rooted trees, as near a spring or small seepage area. These may be identified in the field during reconnaissance or location of cutting lines.

Wind damage can be expected in areas where wind velocity is accelerated by topography. As mentioned earlier, these include the shoulders of a mountain, nose of a ridge, lee of a saddle or gap in a ridge, small ridges in the lee of a higher ridge, and on flats downwind from steep slopes.

Tree height is an important factor. An area may be vulnerable to storm damage, yet safe for the time being because the trees are small. For example, Malmberg (1965) found that stands less than 100 ft (30 m) tall, both unthinned and thinned, generally withstood the severe storm of October 1962.

Predictions of wind damage have been made with Sitka spruce in Great Britain by linking up two kinds of information. The first is wind tunnel data on the force of wind on trees. Force varies with wind velocity and tree size. The second comes from field measurements of the force needed to pull over trees. This varies with tree size and soil type. Both kinds of data can be expressed as the turning moment at the base of a tree. Curves showing the relationship between critical wind velocity and height of trees growing on various soils have been developed. For example, a wind velocity of 40 knots (74 km) per hour becomes critical for a tree 70 ft (21 m) in height growing on a brown earth, 60 ft (18 m) on deep peat, and slightly more than 50 ft (15 m) on a surface water gley (Fraser and Gardiner 1967). Probability of windthrow associated with tree height in Wales has resulted in a recommendation to harvest Sitka spruce on exposed sites with gley or peaty gley soils when trees reach 55 ft (17 m) in height (Stumbles 1968).

Shorter rotations and therefore shorter trees are being dictated by economic conditions. There are many areas where wind damage has been a problem in overmature stands but where trees in intensively managed stands will be cut before reaching wind-susceptible heights.

Reducing Wind Damage

Wind damage can be reduced substantially by silvicultural practice but cannot be eliminated. One approach is to shield susceptible trees from the wind by leaving buffer strips of windfirm trees or by progressive strip cuttings toward storm winds. Another approach is to improve stability of individual trees by increasing rooting depth, strengthening the bole, or lowering the center of gravity of the crown. Rooting depth may be increased by improving soil drainage. Strengthening the bole and lowering the tree's center of gravity can be done through thinning and tending for many years. These measures are costly and are limited to young stands. Trees may be cut as they grow to wind-susceptible heights. It is helpful to minimize the length of cutting boundary exposed to storm winds. This can be done by harvesting large clearcut units, considering, of course, other factors that may limit unit size. Large units also permit more flexibility in locating stand borders in windfirm locations. Some damage will occur in spite of all precautions that may be taken, so it is wise to locate roads near high hazard areas.

Protecting Wind Hazard Areas

When areas to be logged are laid out, an initial step is to identify areas with shallow-rooted trees, high wind velocity, and a history of wind damage. A second step is to determine the direction of storm winds. Winds may follow the general pattern, from southeast to southwest; or they may be redirected by local topography. There may be a strong potential for east wind; for example, near the mouth of the Columbia River between Oregon and Washington or near the Stikine or Taku Rivers in southeast Alaska.

When the hazard area is identified, one alternative is to harvest all the trees within it at one time and to take care that the cutting boundary on the lee or downwind side of the clearcut is in a more stable stand. Another alternative is to leave the entire area uncut, with a stable stand or edge to windward for protection. Usually a satisfactory alternative is to harvest the downwind portion of the hazard area if the downwind cutting boundary is on high ground. This leaves the upwind stand border of wind-susceptible trees exposed but on the windward side of the clearcut where the border trees are protected by the stand to windward. This is not a satisfactory alternative if the area is also subject to occasional storm winds from the opposite direction. An example would be when the main damage comes from southwest storm winds but occasional damage results from easterly or northerly bora winds. The least desirable alternative is to harvest the upwind portion of the area. This leaves a border of susceptible trees fully exposed to storm winds and invites maximum storm damage.

Special care should be taken if clearcut boundaries are to be located in areas where airflow will be accelerated by topography.

Cutting areas should be arranged to avoid leaving exposed stand borders in such locations. Where this is not possible, the exact location of the cutting line should be selected with great care to make it as windfirm as possible. Boundaries on the windward side of clearcuts--numbers 1, 3, 5, and 7 in figure 63--are protected by the trees to windward and should be more windfirm than boundaries on the lee side of clearcuts--numbers 2, 4, 6, and 8. Since storm damage in uncut stands is more common in the lee of a ridgetop, boundary 2 should be considerably more windfirm than boundary 4 (Ruth and Yoder 1953). Boundary 6 probably is more windfirm than boundary 8 in figure 63 because lee flow probably will not follow down a slope as steep as the one illustrated. In gently rolling topography on a lee slope of a ridge, boundary 6 probably would be less windfirm than boundary 8 on a windward slope.

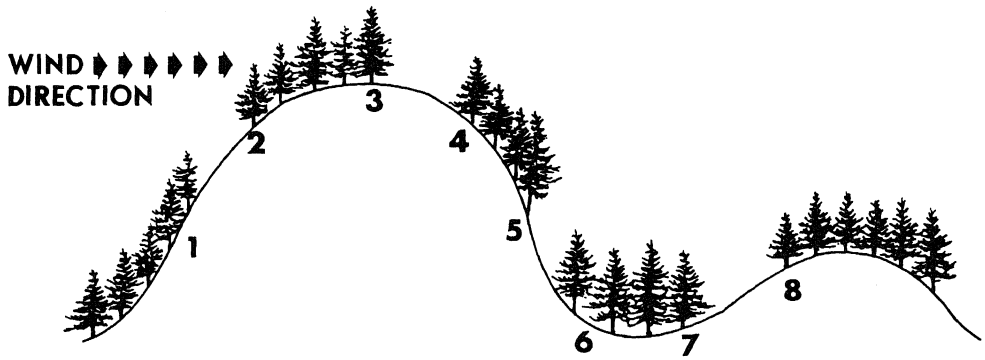

Figure 63.--Vulnerability of clearcut boundaries to wind damage. Boundary numbers 1, 3, 5, and 7 are protected by trees to windward and can be considered more windfirm than numbers 2, 4, 6, and 8.

Locating Cutting Lines

Careful location of cutting boundaries is very effective in minimizing wind damage. One of the first rules is to avoid funneling storm winds through a narrow opening or into a corner, which would increase wind velocity and thereby invite damage. If storm winds are likely to parallel a boundary, the boundary should be as straight as practicable. Avoid changes in direction that expose border trees to the wind. It is best if the boundary angles away from the downwind direction. This way winds will blow over the stand and into the cutover area rather than vice versa in which case trees would be fully exposed to the wind. To be effective, such an arrangement could vary from a straight line perpendicular to the wind to a "V" with the apex pointing into the wind. Of course, should winds blow from the opposite direction, they would be funneled into the apex of the "V" and could cause damage.

Young conifers, alder or other hardwoods, scrub stands as found near a muskeg, and mixed alder-conifer stands are generally windfirm and make good stand borders to leave exposed to storm winds. Cutting areas should be arranged so that windfirm stands form the exposed cutting boundary.

Just as the general location of an exposed cutting boundary may be selected to minimize wind damage, so may the specific location.

Much may be accomplished by moving the cutting line only a short distance nearer to or farther from the landing so that wind-susceptible trees will be harvested and the most windfirm trees left exposed along the cutting line. Windfirm trees are those in the upper crown classes--deep-rooted trees, cedars, Douglas-fir, Sitka spruce, trees without root or stem rot, and trees without damage to the root system. Often they are characterized by large leeward prop roots, indicating a buildup of wind resistance.

Trees whose root systems have been damaged by road or fireline construction or for tail holds in grapple yarding operations are poor risks and should be removed during logging. It is best, of course, to locate the road or the fireline far enough within the cutting area that root damage does not occur to residual trees.

Progressive Strip Cutting

Progressive strip cutting toward storm winds minimizes storm damage on the lee side of clearcut areas. The method was developed in Europe early in the 19th century (Troup 1952); its use with wider strips has been recommended for Western United States forests (Alexander 1964, Boe 1966), including the hemlock-spruce type (Ruth and Yoder 1953). The objective is to avoid creating a lee cutting boundary in stands exposed to storm winds. This is done by cutting the first strip roughly perpendicular to storm winds and immediately windward of a windfirm stand or a natural opening, such as a meadow, muskeg, or open water. After the first strip is regenerated, a second strip is cut windward of the first, and so on progressively into the wind. Cuttings are timed to progress across the area in a rotation. At the end of the rotation the profile of the regenerated stands forms a wedge, pointing into the wind which lifts the airflow up and over the stand (fig. 64E). Cutting of the new crop begins where the first strip was cut and similarly progresses into the wind.

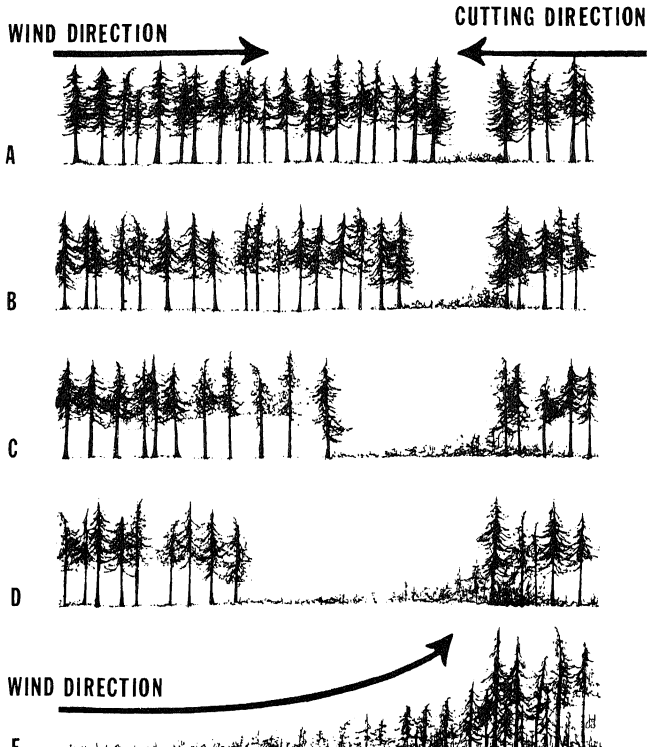

Figure 64.--Progressive strip cutting into the wind to develop a windfirm stand border (see text).

If no opening is available as a starting point for progressive strip cutting, a logical location is the downwind boundary of the ownership, usually the north or east boundary. If cutting must begin within a hemlock-spruce stand, a windfirm location should be picked for the boundary, just as should be done anywhere border trees are to be exposed. In any event, no more than a single stand border will be exposed for the entire progressive strip cutting cycle. This compares with many miles of exposed stand border left by

patch cutting. In many cases strip cutting will prove impractical, but variations may be used to fit local conditions. One variation is to harvest alternate clearcuts along the strips and thereby leave a seed source on three sides. When these clearcuts have regenerated, the intervening timber is cut and alternate clearcuts are harvested in the second strip. This approach was fitted to an uneven ownership pattern along the northeast boundary of a progressive strip demonstration on the Cascade Head Experimental Forest (Ruth and Yoder 1953).

Timing of strip cuttings may be varied to meet local needs. Often the next strip to be cut is needed as a seed source and cutting is delayed until regeneration is obtained. In Alaska, the cost of setting up a logging camp may limit harvest cutting to only a few entries per rotation. Elapsed time between strips may be many years, but progressive strip cutting still is possible by harvesting the downwind portions of the area first and progressing into the wind with successive cuttings.

Developing Windfirm Stand Borders

Windfirm stand borders may be developed by progressive cutting in very narrow strips (Troup 1952). The first strip is harvested immediately windward of the stand to be protected and should be wide enough that exposed border trees will be stimulated to become more windfirm, but not so wide that they will be broken or uprooted (fig. 64A). Local experience with storm damage along road rights-of-way perpendicular to storm winds can be used as a guide for strip width. Natural regeneration or planted trees that become established in this first opening are the beginning of the windfirm stand border. Border trees in the stand to be protected, now receiving more light, will retain and develop lower branches.

As soon as these border trees become more windfirm, a second strip may be harvested (fig. 64B). Trees should be felled within the strip to avoid damaging regeneration established in strip 1. The additional light stimulates regeneration in strip 1 to accelerate height growth. New seedlings become established in strip 2. The increased exposure of border trees to wind provides added stimulation to develop windfirmness. Successive strips are cut to windward over a period of years, the timing depending on stability of the border trees in the stand being protected and on height growth of the new stand (fig. 64C). The slower the rate of cutting to windward the steeper the profile of the new windfirm stand border. When protection afforded by the young border stand and the increased windfirmness of border trees in the original stand are sufficient, the windfirm stand border is considered established. The timber stand to windward may then be clearcut or otherwise treated as desired. The original leeward stand now is protected by a windfirm border that lifts storm winds up and over the edge of the stand (fig. 64D).

A similar procedure may be used with shelterwood cutting. In a two-cut shelterwood, for example, strip 1 receives a shelterwood cut. After regeneration is established in the shelter of the remaining overstory, the overstory is removed, and strip 2 receives a shelterwood cut. Additional cutting of shelterwood strips progress to windward in the same manner as for clearcut strips.

There have been several attempts in Europe to develop windfirm stand borders by severe pruning. About three-fourths of the crown of

edge trees may be removed. Severity of pruning decreases toward the interior of the stand until at about 150 ft (45 m) from the edge pruning stops. Pruned trees are more stable because they have less crown area, yet they break the wind and protect the interior of the stand. Several variations of this technique, such as topping the trees or pruning all windward branches, have been tried but none have been successful enough to become standard practice (Busby 1965, Neustein et al. 1968).

Stumbles (1968) described a technique used in Wales designed to improve stability of trees that will later be exposed along a stand border. Several years in advance of harvest cutting the cutting boundary is located on well-drained soil where exposure of trees may be expected to improve their windfirmness. Windfirm trees are selected in the first 130 ft (40 m) within the stand that will be exposed to the wind. Surrounding trees are then harvested in a heavy crown thinning. This allows several years for trees that will be exposed to adapt to increased wind pressure. If the stand to be exposed is young, a 66-ft-wide (20-m) strip of the older, windward stand is harvested several years in advance; this gives border trees of the young stand time to adjust to increased wind pressure.

Stabilization of a Stand Border After Wind Damage

In many situations wind damage associated with harvest cuttings tends to diminish with time (Ruth and Yoder 1953; Weidman 1920; Alexander 1964, 1967; Busby 1965). The more susceptible trees are uprooted or broken soon after exposure, leaving only the more windfirm trees standing. These tend to build up windfirmness. If leaning trees are left by the storm, they remain susceptible and continued mortality can be expected (Wiley 1965).

The scattered trees that remain standing along the edge break the wind and provide some protection for trees to leeward. Farther in, more remain standing and these, in turn, divert more of the wind. This process continues until the wind is again lifted up and over the forest canopy. When the wind filters through a border of widely spaced and well-rooted trees, rather than being forced up and over a fully stocked stand edge, it is less likely to eddy down and strike inside the stand.

If a few additional trees blow down in subsequent storms, it may be best to salvage down, damaged, and leaning trees only, being careful to avoid damaging roots of trees to be left. Several salvage efforts may be needed before the line stabilizes. Many factors will influence salvage attempts. For example, repeated salvage is impractical at remote locations in Alaska but is easily accomplished in readily accessible areas in Oregon and Washington. The decision will also be affected by availability of equipment, market conditions, and cutting schedules.

If the stand border is located where tree stability is poor, it is best to harvest the remaining trees and move the cutting line to a more windfirm location. Fraser (1965) found that wind damage on poorly drained peat soils in Britain, once started, tended to continue at an accelerating rate and frequently stopped only when there was a change in soil type, tree size, or forest type.

Improving Tree Stability

Experience in Great Britain and elsewhere has shown that when poor drainage restricts rooting depth, resistance to uprooting can often be increased by silvicultural treatment. A high water table can be lowered by drainage, thereby improving rooting depth and mechanical strength of the soil. Drainage has been particularly successful in deep peat soils in Great Britain, because it not only increased rooting depth and windfirmness but also improved yield capacity (Taylor 1970, Stumbles 1968). Soil drainage is best accomplished at the time of planting but still remains a profitable operation in Britain up to 10 years afterward (Fraser 1965). Some soils, however, will not drain properly even with ditching (Day 1953). Within the hemlock-spruce type, attempts to increase windfirmness by improving drainage have not been made.

Just as any action that lowers the water table increases tree stability, any action that raises it can be expected to cause root dieback and loss of stability and may provide an entry court for disease. An example, particularly disastrous in flat topography, is plugging a stream channel with logging debris. Dams made by beavers, construction of reservoirs, and removal of vegetation can cause similar problems. The effect on the water table and subsequent wind damage and root disease should be considered.

Leaving dense stands unthinned affords maximum protection of each tree by its neighbors. If the stand border is destroyed by wind or other disturbance, however, damage is likely to spread through the stand. If thinnings are prescribed, they should be done early in the life of the stand and tested on a small scale until results can be ascertained. A single precommercial thinning may be all that is appropriate in wet areas. If treatments can be applied to lower the soil water table, rooting depth should improve, and subsequent thinnings may be practicable.

It is advantageous to thin exposed stands after the season when high winds occur and prior to the growing season. This gives the residual stand at least one season to build up windfirmness before exposure to storm winds.

Salvaging Blowdown

Organizing for salvage of windthrown timber varies considerably, depending on the extent of damage. Salvage of catastrophic blowdown is usually coordinated by a committee made up of governmental agencies and interested parties. A necessary first step is to determine the location and magnitude of damage. Usually this is done by aerial survey, and the blowdown areas are sketched on a map. Later the areas are examined on the ground by the timber owner and detailed salvage plans made. The volume to be salvaged may exceed the allowable cut and mill capacity for the local area. Then consideration must be given to transporting logs outside the area and the effect this will have there.

Salvage of casual blowdown normally is a concern only of the timber owner. If the forest has a fully developed and maintained road system, small patches of down timber and even scattered, individual trees can be salvaged before decay develops. Often this is the case in Oregon and Washington. In Alaska accessibility varies. Some areas

remain readily accessible throughout a rotation. Others may require extensive road maintenance or setting up a logging camp which may be impractical for small timber volumes. The fact that wind damage is a common problem in hemlock-spruce forests is an argument for maintaining main access roads to all parts of an ownership and keeping them available for salvage operations.

If blowdown cannot be removed the first summer, special effort should be made to get it out before the second. Decay of sapwood can be expected to accelerate with time. If only one salvage entry is planned and additional blowdown is anticipated, it may be best to accept some loss of sapwood and wait until the second or third season for salvage. This will permit salvaging additional blowdown that may occur.

Cost of salvaging blowdown timber is higher than for logging standing timber (Stumbles 1968, Fraser 1964, Crawford 1968, Binkley 1964). Windthrown trees are often criss-crossed (fig. 65). They may be under bending stress, making bucking more dangerous than under normal conditions. Yarding the logs costs more because of hangups due to root wads and high stumps. If decay has begun, the defective material on the outside and at the ends of logs is necessarily handled

Figure 65.--Salvage of windthrown timber is dangerous and costly. Bent stems are under great stress and, when bucked into logs, may injure loggers. Shrubby Island, Alaska.

throughout the logging operation. Net scale will be considerably below gross scale and costs will be proportionately higher than for sound material. Unexpected changes in logging plans to accommodate salvage operations usually result in increased costs.

Discussion

There are two main periods in the life of a forest when special attention should be given to wind. The first is during establishment of the stand. There are areas where forest yield will be restricted by the wind to the extent that it will be best to forgo timber production and designate the land for another use. In this event, it may not be appropriate to establish a forest at all or perhaps to establish only clumps of timber in sheltered locations. Most such areas are near timberline and the north and west extremities of the hemlock-spruce type. In these and similar areas, the trees should be widely spaced so they will develop under wind stress and build up wind resistance.

The second period requiring special attention begins when decisions must be made about thinning and continues up to and including harvest cutting. If improperly done, thinnings contribute to wind damage and can result in economic loss. The land manager must evaluate the wind hazard and other factors and decide what degree of thinning, if any, is appropriate.

If a thinning regime is to be instituted, it is best to begin early in the life of the stand. When trees develop in dense stands, they become more dependent on their neighbors for protection and, therefore, more vulnerable to damage when their neighbors are removed. Generally on deep soils, careful thinning will improve tree stability; although immediately after thinning, the stand will be more vulnerable than before. Where rooting is restricted and most root extension is lateral, thinning may increase wind exposure more than it improves rooting.

Tree height is of major importance in timing harvest cuttings in areas of wind hazard. Throughout the rotation, the forest manager tries to improve tree stability. But in a way this is a losing battle because height growth continuously erodes tree stability by increasing the length of the lever arm working on the stem and the root system. Tree height is the major variable remaining under control of the forest manager.

If the forest manager has a serious problem with damage from wind, there is a tree height above which wind damage becomes a definite risk. There will be a yield loss if this height is below that needed for an economic rotation. The forest manager must weigh the increased risk of wind damage against the increased return from keeping the stand to its economic rotation age. The decision can range all the way from harvesting when wind first becomes a risk to holding the stand to rotation age regardless of wind.

In the first instance, economic loss is certain because the trees will be cut before maturity. In the second, the loss is harder to predict. It depends on the accuracy of predictions of wind damage. The best alternative probably lies between these extremes. A few feet of height increases the value of the crop, and this is worth incurring

some additional risk of wind damage. The best solution for a particular stand will depend on these and many additional factors, including such items as feasibility of salvage operations and markets for small logs.

Careful management can minimize wind damage but can never prevent it entirely. No matter how effective the management to minimize wind damage, catastrophic storms can be expected to occasionally disrupt management plans. The manager's best defense is to develop flexibility and to prepare contingent plans for salvage of windthrown timber. Good access to timber stands is a key factor. Management prescriptions will be most effective in dealing with losses between catastrophes; but the catastrophic storm must be dealt with and there are lessons to learn from it.

MULTIPLE USE

Timber is a major resource throughout the hemlock-spruce type; but soil, air, water, range, recreation, esthetics, wildlife, fish, and minerals are important resources as well. Timber harvesting affects all resources, and all must be considered in forest management decisions. Multiple use of resources is practiced to various degrees throughout the hemlock-spruce type. The degree depends on forest ownership, suitability of the land, and relative demands for various resources. Emphasis on multiple use is strongest on Federal lands where it is required by law. The States of Alaska, Oregon, and Washington have also enacted legislation concerning multiple use of resources.

Private forest landowners are not legally bound to practice multiple use to the same extent. However, State and Federal water pollution laws and State laws regulating fish and wildlife require private landowners to protect streams and lakes within their properties. Laws pertaining to air quality also affect management practices on private land. Most owners of large tracts allow the general public access to their property for the use and enjoyment of fish, game, or recreational resources. Esthetics or visual resources are often protected where major highways cross industrial forest lands. So to various degrees, multiple use is a concern of virtually all forest managers.

The multiple-use concept does not mean that every use occurs on every acre. Obviously, not all resources are available on each acre nor are all uses compatible. Careful inventory of available resources and of public and private objectives is essential, followed by allocation of land for various uses. In most cases, several uses on the same area or adjacent areas must be reconciled. Planning then is the key to successful application of the principle of multiple use. An example of this is the planning process now being done on the Tongass National Forest (USDA Forest Service 1977).

The silviculturist may contribute substantially to the planning process through knowledge of stand conditions and the capability of the land for tree growth. Once management decisions regarding allocations have been made, the silviculturist can help to prescribe the best cultural treatments from among those known to be biologically sound for use in the hemlock-spruce type.

SILVICULTURAL SYSTEMS

Clearcutting is widely practiced where timber production is the dominant use. Guidelines have been developed; if followed, these guidelines will minimize adverse effects of clearcutting on other land uses. Often the key to mitigating conflicts is simply adequate supervision of timber sales or other management activities. Separation of conflicting land uses can be effective in many cases. Other silvicultural systems could, theoretically, be used to good advantage where clearcutting is incompatible with other land uses; for example, when maintenance or modification of an existing timber stand is desired. Campgrounds, streamside or beach stands, deer winter range, and roadside stands are examples of situations where a combination of high forest and small openings may be desired. At present in the western hemlock-Sitka spruce type, we have few demonstrations of benefits from alternative silvicultural systems. Silvicultural practices to better integrate land uses should be developed. Examples of important multiple-use considerations in the hemlock-spruce type follow.

WATER AND FISH HABITAT

Water and fish are resources that are especially important in coastal forests (fig. 66). In Alaska especially, forests and waterways

Figure 66.--Fish and timber resources are closely related in the hemlock-spruce forests. A typical stream used by salmon and trout for spawning and rearing. Montana Creek near Juneau, Alaska.

are closely interwoven. In southeast Alaska alone there are 9,000 mi (15 000 km) of coastal shoreline and numerous lakes and streams on the mainland and islands. More than 1,100 streams are estimated to be used by salmon (Schmiege et al. 1974).

Timber management activities must be carried out in a manner that will assure protection of water quality and fish habitat. Research has shown that damage can occur in many ways but that damage need not occur.

One of the most obvious ways logging may affect streams adversely is from the introduction of logging residue. Logs, limbs, and tops of trees can block passage or occupy space in rearing areas that could otherwise be used by fish (Meehan 1974). Small debris--such as bark, twigs, and leaves--can reduce food supplies for rearing fish by filling the gravel interstices and interfering with stream invertebrates (Ponce 1974) (fig. 67). Logging debris may reduce water quality by blocking water flow and reducing dissolved oxygen supplies (Narver 1971, Reed and Elliott 1972).

Figure 67.--Small residues (such as bark and wood chips, twigs, and needles) damage fish habitat in spawning and rearing streams. Seal Bay, Chichagof Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game).

Above the high water marks, burning of logging residues may affect water quality if the fire is hot enough to consume surface organic material. Additional mineral soil is exposed, and soil trapped by residues may be released. Generally, erosion from prescribed burning is not a serious problem in coastal areas because the percentage of exposed soil is not greatly increased (Morris 1970). Also, developing vegetation may stabilize the soil before it reaches a stream. In special situations, however, burning may contribute to

stream sedimentation; this possibility should be evaluated when plans for managing residues are developed.

Burning may reduce the infiltration rate of water into the soil (Austin and Baisinger 1955), and this temporarily tends to increase peak overland flows. To the extent live vegetation is damaged or killed by fire, transpiration is reduced and more soil water is available for streamflow.

Summer stream temperatures increase when streamside vegetation is removed. For example, Meehan et al. (1969) found that in Alaska after complete clearcutting of about 7 mi (11 km) of main stream in Harris River and 5 mi (8 km) of Maybeso Creek, maximum stream temperatures rose from 4°F (2°C) to 9°F (5°C), for the months of April through September. The temperature increase depends on such factors as streamflow, length of channel exposed by clearcutting, groundwater, and general climatic conditions. Temperatures increase more farther south, and a method of predicting the effect of clearcutting on stream temperature has been developed (Brown and Krygier 1970).

Water temperature in small streams may increase dramatically during burning of residues. A severe instance occurred in Needle Branch, a V-shaped valley with steep slopes, on the Oregon coast. Stream temperature rose from 55°F (13°C) to 82°F (28°C) during slash burning. This increase was enough to kill many juvenile coho salmon, cutthroat trout, and sculpin. The population of cutthroat trout was severely affected for a long period; the population levels of other fish returned to normal within 2 years (Hall and Lantz 1969).

Chemistry of surface waters may be altered by timber management practices, such as clearcutting, burning, fertilization, and the use of pesticides. Clearcutting has been shown to increase soil temperatures in the hemlock-spruce type (Gregory 1956). Such increases are known to increase biological decomposition rates and thereby release nutrients which may enter stream water. For example, a study in Alaska showed some significant changes in soil and surface waters associated with clearcutting (Schmiege et al. 1974), as indicated in table 8.

Table 8--Nutrient content of soils and surface water before and after timber harvest[1/]

Nutrient	Surface water (creeks)		Soil water			
			Tokeen soils, well drained		Wadleigh soils, somewhat poorly drained	
	Timbered	Clearcut	Timbered	Clearcut	Timbered	Clearcut
	Milligrams per liter					
Nitrate	0.062	0.094*	0.055	0.116*	0.067	0.195*
Phosphate	.86	1.04	1.02	.914	.76	.915
Iron	.07	.15*	.1	.07	.1	1.30*
Calcium	1.72	1.45	1.30	2.23*	1.38	2.35*
Magnesium	.185	.24	.16	.34*	.20	.17
Potassium	.52	.85*	.35	.70*	1.68	2.65*
Sodium	1.12	1.16	1.60	2.26*	1.15	1.15
Organic carbon	4.8	6.3	7.0	12.5	7.0	30.0*

*Indicates that differences between samples from clearcut and timbered areas are probably real, judging by the magnitude of difference and variation between duplicate samples. Analysis by Federal Water Quality Laboratory, Fairbanks, Alaska.

[1/] USDA Forest Service Environmental Statement, Ketchikan Pulp Company Timber Sale 1974-1979 Operating Period. On file, USDA Forest Service, Juneau, Alaska.

Organic compounds may be leached from logs that are stored or transported in water. Pease (1974) found high concentrations of these chemicals at log raft storage sites in Alaska. Such leachates can be toxic to salmon fry. Bark and other debris from logs can form an impervious bottom layer in bays and estuaries where logs are stored (Ellis 1970), affecting animals such as crabs and clams.

Chemicals such as pesticides and fertilizers may be introduced into streams from silvicultural operations (Norris and Moore 1971, Meehan 1974). Different degrees of toxicity to fish by various formulations of the same pesticide have been demonstrated (Sears and Meehan 1971). Meehan (1974) pointed out that the behavior of each chemical formulation and the effects on aquatic life must be known before widespread application.

Increased sedimentation reduces water quality and degrades fish habitat. Suspended sediment directly reduces water quality and may damage fish and fish habitat by increasing turbidity, thus hampering access to food by fish that feed by sight (Phillips 1971). More important though is damage from sediment deposited in spawning gravels. This sediment can block free flow of oxygen-carrying water and fill gravel interstices and thereby damage eggs or alevins (Cooper 1965, McNeil 1966, Vaux 1962). Sedimentation may be caused by logging and roadbuilding; roadbuilding is usually the greater contributor (Swanston 1971).

In Alaska, mass wasting or landslides are common in unlogged watersheds and contribute to stream sedimentation. In some cases the frequency of mass movement has been shown to increase greatly after clearcutting. The problem is discussed in more detail on page 101.

It is now recognized that from an economic standpoint, fisheries values can often exceed the value of timber within 100 ft (30 m) of a stream (Sadler 1970). Thus the protection of streams through silvicultural management of streamside vegetation is receiving greater attention.

In British Columbia narrow strips of vegetation, commonly referred to as leave strips or fringe strips, are now often left along streams for protection where clearcutting is done (Burns 1970, McMynn 1970). Leave strips are subject to damage by wind, and forest managers have been reluctant to include them in management plans. Efforts are being made to understand factors associated with blowdown of streamside leave strips and to provide guidelines that will help to make possible the design of more stable leave strips (Moore 1977).

Improved management prescriptions designed to protect the streams and still allow harvest of valuable timber from streamside stands are needed.

WILDLIFE

Hemlock-spruce forests are habitats for many species of wildlife. Wild mammals may, in some cases, damage trees and stands, as was noted in a previous section; but the limited damage that occurs is usually overshadowed by the benefits derived from wildlife. Wildlife species

provide recreation and enjoyment to people, and some animals are used as food. Trapping of fur bearers is an important source of income for a few people. Animals often serve as vital links in maintaining a productive forest ecosystem.

Logging drastically changes the forest ecosystem and so may cause changes in composition and relative abundance of wildlife. Studies elsewhere show that some species of wildlife respond favorably to logging, whereas others suffer because of loss of suitable habitat. If a management plan includes some predetermined mix and density of animal species, it must allow for the habitat needed.

Management of wildlife is the responsibility of each State. The management of wildlife habitat, however, is largely the responsibility of forest landowners and managers. Only through cooperation can good wildlife management be assured.

Big game animals are especially important from the standpoint of hunting and general esthetic enjoyment. Many big game species occur within the hemlock-spruce type. Deer and black bear are found throughout. Elk occur in Oregon and Washington but in Alaska are found only outside the hemlock-spruce type. Brown bear, wolf, mountain goat, and moose are found within the hemlock-spruce type in Alaska.

In portions of the hemlock-spruce type toward the south where winter snow is light, clearcutting, burning, or otherwise opening up of old-growth stands may improve conditions for deer (Cowan 1945, Mitchell 1950). Toward the north, however, where snow is the major factor limiting populations, the low-elevation, old-growth forest is critical for survival of deer during periods of severe weather (USDA Forest Service 1977, Alaska Department of Fish and Game 1977). Clearcutting may reduce the amount of suitable deer habitat. Summer forage may be increased for several years after clearcutting as forbs, grass, and woody plants proliferate, but summer forage is usually more than adequate without logging. During the winter, forage on clearcuts is largely unavailable to deer because of deep snow (Jones 1975, Merriam 1971).

In southeast Alaska, most cutover areas regenerate quickly to dense stands of hemlock and spruce and soon shade out forage plants. Such stands may offer cover for deer but provide little available forage. Within the rotation period, the forage supply for deer may not regain the levels that occur under old-growth forests.

Periodic thinning and the use of silvicultural systems other than clearcutting in some areas could conceivably maintain or improve deer habitat, although this is yet to be demonstrated. Quantitative area-by-area information is needed on the habitat requirements of deer and on the ability of various forest stands to supply those requirements under natural conditions and under management.

Black bear may benefit from clearcutting because of increased food supplies. During much of the year, berries and other plant material make up a large part of a bear's diet; and many edible plants are among the early pioneers on cutover land (Erickson 1965) (fig. 68).

Brown bear are found in the hemlock-spruce forests of Alaska. Tidal flats and alpine areas are important feeding areas during some

Figure 68.--Bear depend on berries and other plant material for food during much of the year when salmon are not available. A brown bear on the Pack Creek, Admiralty Island, Alaska.

seasons, and salmon are an important part of the bear's diet during the fall. Hemlock-spruce forests offer cover for brown bear, and most feeding on tidal flats and beaches is along a forested fringe (Perensovich 1964).

Logging is not expected to have a direct effect on brown bear populations, but the presence of camps and people may cause changes. So far there appears to be no general shift of bear populations from present cutting areas.

Proper garbage disposal, so as not to attract bears, would eliminate much of the killing of "nuisance" animals. Around permanent or seasonal communities, brown bears are often eliminated to protect people or property. Fishermen often shoot bears because they are believed to be a competing predator (Meehan 1974).

Bald eagles are plentiful in southeast Alaska, with an estimated breeding population in excess of 8,000 birds (King et al. 1972). Nests are mainly built in old-growth trees, nearly always within several hundred feet of shorelines (Meehan 1974). Bald eagles are endangered species in most areas of the United States and receive special protection in Alaska. Nesting sites are carefully protected, and no timber cutting can be done within a 5-chain (100-m) radius of a nest tree (USDA Forest Service, Alaska Region).

Other species of game and nongame animals and birds occur within hemlock-spruce forests, but in most cases little is known about their habitat needs. This is especially true for nongame species (fig. 69). The recent increase in environmental awareness and dramatic changes in patterns of wildlife-related recreation are doing a great deal to change this picture (DeGraaf 1978). The forest manager must be ready to modify practices when necessary in the light of new information.

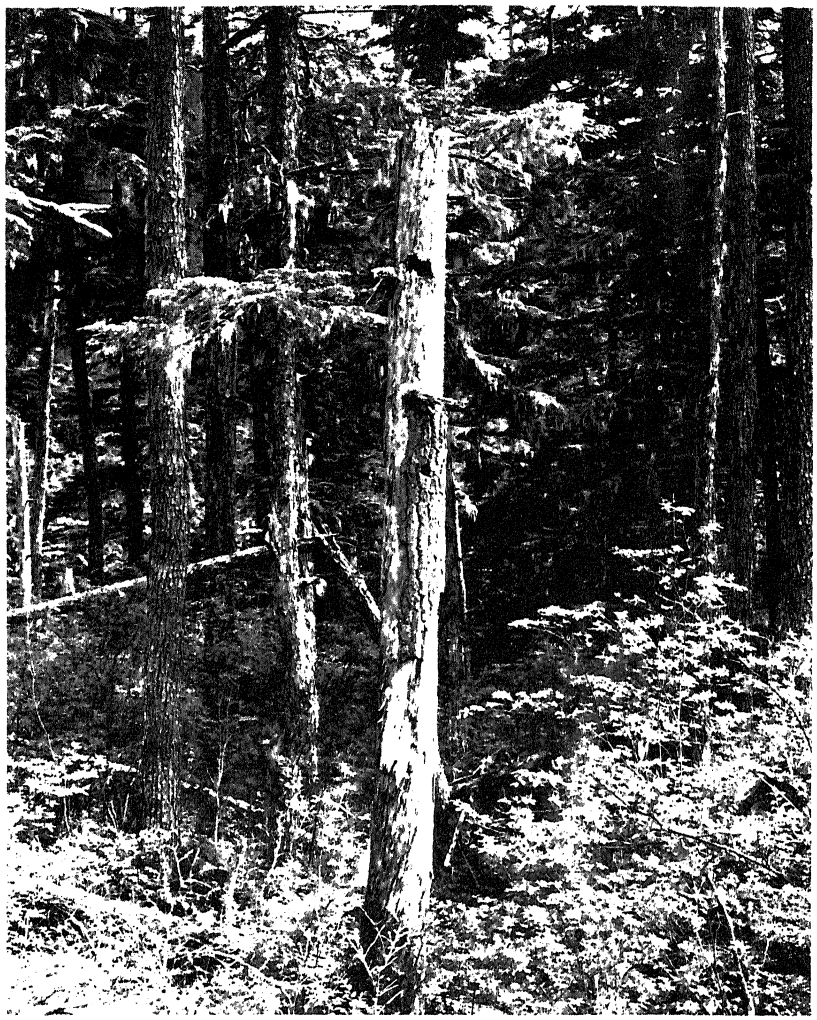

Figure 69.--Snags in old-growth stands provide nesting trees for birds. Tee Harbor, Alaska.

RECREATION AND ESTHETICS

Recreation and esthetic enjoyment are long-established values of forest land. Along with recreational activities, concern about the quality of the visual environment has been increasing. Because of this concern on the National Forests, it has become appropriate to establish the "visual landscape" as a basic resource, to be "treated as an essential part of and receive equal consideration with the other basic resources of the land."[25/]

25/ Forest Service Manual Chapter 2380 - Landscape management. FSM 2/77 Amend. 74. U.S. Gov. Print. Off. 1977-241-420/FS-25.

The emphasis on visual quality has led to the incorporation of landscape management as an integral part of land management on the National Forests. The basic concepts of landscape management and methods of practical application have been described (USDA Forest Service 1973, 1974). In general, the objectives in relation to timber management are to retain or enhance scenic quality and to make human activities less obtrusive.

Landscape management and timber management are inseparable in the hemlock-spruce type. The combination of dense commercial forests reaching down to the sea, water-oriented recreation and esthetics, and clearcutting as the basic silvicultural system means that the landscape architect and timber management specialist must work together closely to maintain acceptable visual standards. Clearcutting units can be shaped and placed to be less obtrusive. Cutting boundaries, however, must be windfirm to avoid loss of timber around edges.

With recreational use of coastal forests mostly water oriented, distant views of cutover areas are particularly important (fig. 70). Color and general appearance are major factors. During the 1st year after clearcutting, logging debris, stumps, and the organic duff layer are brown, contrasting with the green of surrounding timber. From the 1st to 4th year, green plants cover the ground. Stumps, logs, and tops bleach to a gray. The green plants blend with surrounding timber, and the major contrast is between adjacent ground vegetation and the gray of the residues. From 5 to 8 years after clearcutting, residues become covered by ground vegetation and major contrasts disappear. A new hemlock-spruce forest canopy usually closes over the area 15 to 20 years after clearcutting.

Figure 70.--The visual effects of clearcutting are evident along the inside passage in Alaska.

Residues contribute substantially to an impression of forest devastation after clearcutting. Although public reaction to timber harvesting usually focuses more on the loss of tree cover than on the logging debris, the presence of large amounts of residue is taken by many people as evidence of forest devastation (Wagar 1974) and as a waste of wood fiber. Direct contact with forest residue is of greatest concern in areas of high public use, usually near roads and campgrounds where berrypicking and hunting are important.

Snags are a special component of forest residue, especially important in old-growth forests. The esthetic value of snags is, of course, subjective and will be judged differently by different people (fig. 71). Snags often have value as nesting sites (Scott et al. 1977) but may also interfere with timber management activities. Conflicts, based on concern for safety and on concern for various resources, may develop over the disposition of snags. Blanket rules governing disposition of snags on all cutover areas are not desirable. Ideally, a compromise solution for retention of snags on each cutting unit should be worked out by various management specialists.

Figure 71.--Eight years after logging, most residues are hidden by conifers but snags remain in view. The esthetic value of snags varies by their numbers and distribution and by the individual tastes of viewers. Maybeso Valley, Alaska.

The adverse esthetic effects of logging residue may be directly reduced by rearranging or reducing the amount of residue left after logging; indirectly by separating people from timber harvest operations

and perhaps by education to show the public why residues are created and some of their positive benefits. Some combination of the following actions would improve postharvest esthetics in the hemlock-spruce type.

1. Improve utilization. Better utilization would directly eliminate much of the problem, especially that of large residues.

2. Clean up foreground areas along travel routes. The condition of the foreground has a great effect on one's perception of an entire cutover unit. Also, the greatest public use of cutover areas is adjacent to roads. Yarding and burning unutilized material has application in foreground cleanup.

3. Lay out cutting units, whenever possible, so they are screened from public view. Leaving uncut strips along roadways or waterways and placing cutting units to blend with topography helps reduce adverse esthetic effects. When necessary to cut along travel routes, small cutting units are less objectionable than large ones.

4. Treat residue. Broadcast burning or piling and burning substantially reduces the amount of residue and greatly improves access. Charring of remaining debris causes it to blend in better with the surrounding soil surface and thereby reduces its visibility. Clearcuts revegetate quickly, providing a contrast between the green foliage and burned residue.

5. Educate. The public needs to be better informed about residue management. People will better understand the reality of woods operations if they know the roles played by forest residues in nutrient cycling and forest regeneration and understand the economics of wood utilization.

Residues created by precommercial and commercial thinning and by shelterwood cutting also have esthetic effects but less drastic than those associated with clearcutting. Volumes are less, sizes smaller, and much of the residue is screened from view by the residual stand. Residues from precommercial thinning substantially hamper travel through an area until thinned stems have settled to the ground.

In some situations, clearcutting may be incompatible with landscape management objectives. Some form of partial cutting could allow timber removal while retaining the forest appearance. Silvicultural systems used in connection with partial cutting must be compatible with ecological characteristics of the tree species involved, and timber extraction must be economically feasible.

AIR QUALITY

Air is an essential resource but one usually taken for granted. Pure air is essential to enjoyment everywhere, and only when it becomes polluted do we become aware of the degradation of this resource.

Within the hemlock-spruce type, pure air is abundant, as most prevailing winds are onshore. Where air pollution exists, it is localized around urban or industrial sites. Timber management activities may contribute to local problems. Dust and fumes--along with the

noise of trucks, heavy equipment, and chain saws--are common features of logging activity. Fortunately, these activities are usually located far from urban centers.

Smoke from prescribed burning of forest residues is the primary source of air pollution caused by timber management activities. Effects of prescribed fire on air quality are summarized by Hall (1972). He concluded that, "In general, the only penalty inflicted upon the environment by prescribed burning is a small and temporary decrease in visibility." Burning of forest residues does not produce the sulfur oxides common to combustion of coal and oil. Production of nitrogen oxides is rare. Carbon monoxide and carbon dioxide concentrations were measured near the perimeter of an experimental burn of Douglas-fir residue in western Washington, and high concentrations at the site decreased rapidly to normal in both horizontal and vertical directions (Fritschen et al. 1970; Murphy et al. 1970a, 1970b). Hydrocarbons produced by burning residues are similar to or identical with natural products always present in the environment. Only small traces of low-molecular-weight, photochemically active compounds are produced (Hall 1972).

Close to a prescribed fire, dense smoke may be unpleasant from the standpoint of odor and lung or eye irritation. Locally, it can obstruct visibility to the point of being a traffic hazard. But mainly, smoke and haze obstruct distant views and thereby decrease visibility and enjoyment of the outdoors. Objections to prescribed burning are strongest in urban areas. Problems can be reduced by developing smoke management systems that will keep smoke out of sensitive areas. Such a system requires knowledge of smoke behavior and cooperation between public and private forestry agencies (Cramer and Graham 1971).

The land manager often must decide whether it is better to reduce fire hazard by prescribed burning, with reasonable management of smoke, or to leave the hazard and hope it will never burn. Leaving it runs the risk of wildfire with much greater smoke emission and the possibility that smoke will drift over urban areas. Prescribed fires can be set when airflow will disperse smoke and carry it away from urban areas, when a hot convection column will carry smoke aloft, and when fuel is dry enough to burn with little smoke (Cramer and Graham 1971) The latter is difficult in hemlock-spruce forests compared with drier inland forests. Prolonged smoldering of slash piles produces a lot of smoke which, without strong convection currents, tends to flow at ground level. A mixture of soil in the slash aggravates this problem.

RANGE

Grazing by domestic livestock is virtually nonexistent within hemlock-spruce forests. Stands tend to be dense, with little available forage; terrain is often steep; and climatic conditions are unsuitable. In Oregon and Washington some livestock are grazed on cleared land along streams. In coastal Alaska the only significant grasslands are on tidal flats, but use of these lands for domestic animals has not proved feasible. Grazing by wildlife will continue to be the major use of the small amount of rangeland within the hemlock-spruce type.

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APPENDIX

Common and Scientific Names

Plants

Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
alder, red	*Alnus rubra* Bong.
alder, Sitka	*Alnus sinuata* (Reg.) Rydb.
alder, thinleaf	*Alnus tenuifolia* Nutt.
blueberry, Alaska	*Vaccinium alaskense* Howell
blueberry, early	*Vaccinium ovalifolium* Sm.
bracken	*Pteridium aquilinum* (L.) Kuhn
bunchberry	*Cornus canadensis* L.
cottonwood, black	*Populus trichocarpa* Torr. & Gray
currant, stink	*Ribes bracteosum* Dougl.
currant, trailing black	*Ribes laxiflorum* Pursh
deerberry	*Maianthemum dilatatum* (Wood) Nels. & Macbr.
deerfern	*Blechnum spicant* (L.) Roth
devilsclub	*Oplopanax horridus* (Sm.) Miq.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
dwarf mistletoe, hemlock	*Arceuthobium tsugense* (Rosend.) G. N. Jones
elder, Pacific red	*Sambucus callicarpa* Greene
fir, Pacific silver	*Abies amabilis* (Dougl.) Forbes
fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
five-leaf bramble	*Rubus pedatus* J. E. Smith
hemlock, mountain	*Tsuga mertensiana* (Bong.) Carr.
hemlock, western	*Tsuga heterophylla* (Raf.) Sarg.
huckleberry, evergreen	*Vaccinium ovatum* Pursh
huckleberry, red	*Vaccinium parvifolium* Sm.
lace flower	*Tiarella trifoliata* L.
ladyfern	*Athyrium filix-femina* (L.) Roth
maple, bigleaf	*Acer macrophyllum* Pursh
maple, Douglas	*Acer glabrum* Torr. var. *douglasii* (Hook.) Dipp.
maple, vine	*Acer circinatum* Pursh
menziesia, rusty	*Menziesia ferruginea* Sm.
Oregongrape	*Berberis nervosa* Pursh
oxalis, Oregon	*Oxalis oregana* Nutt. ex T. & G.
pine, shore	*Pinus contorta* Dougl. var. *contorta*
pine, western white	*Pinus monticola* Dougl.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
redcedar, western	*Thuja plicata* Donn
redwood, coast	*Sequoia sempervirens* (D. Don) Endl.
rhododendron, Pacific	*Rhododendron macrophyllum* G. Don
salal	*Gaultheria shallon* Pursh
salmonberry	*Rubus spectabilis* Pursh
saxifrage, western golden	*Chrysosplenium glechomaefolium* Nutt.
skunk cabbage	*Lysichiton americanum* Hult. & St. John
Smith's fairybells	*Disporum smithii* (Hook.) Piper
snow dewberry	*Rubus nivalis* Dougl. ex Hook.
spreading woodfern	*Dryopteris dilatata* (Hoffm.) Gray
spruce, Lutz	*Picea* X *lutzii* Little
spruce, Sitka	*Picea sitchensis* (Bong.) Carr.
spruce, white	*Picea glauca* (Moench) Voss
swordfern	*Polystichum munitum* (Kaulf.) Presl
thimbleberry, western	*Rubus parviflorus* Nutt.
twisted stalk, clasping	*Streptopus amplexifolius* (L.) DC.
violet, evergreen	*Viola sempervirens* Greene

violet, stream	*Viola glabella* Nutt.
waterhemlock, western	*Cicuta douglasii* (DC.) Coult. & Rose
water parsley	*Oenanthe sarmentosa* Presl ex. D.C.
western springbeauty	*Montia sibirica* (L.) How.
willows	*Salix* sp.
woodfern, mountain	*Dryopteris austraica* (Jacq.) Woynar ex Schinz and Thell.

Insects

aphid, spruce	*Elatobium abietinum* (Walker)
beetle, striped ambrosia	*Trypodendron lineatum* (Olivier)
beetle, bark	*Dendroctonus* spp.
beetle, spruce	*Dendroctonus rufipennis* (Kirby)
budworm, western black-headed	*Acleris gloverana* (Walsingham)
budworm, spruce	*Choristoneura fumiferana* (Clemens)
looper, saddle-backed	*Ectropis crepuscularia* (Denis and Schiffermüller)
looper, western hemlock	*Lambdina fiscellaria lugubrosa* (Hulst)
sawfly, hemlock	*Neodiprion tsugae* Middleton
weevil, white pine	*Pissodes strobi* (Peck)

Fungi [1/]

annosus root rot	*Fomes annosus* (Fr.) Cke.
artist's conk	*Fomes applanatus* (Pers.) Gill. = [*Ganoderma applanatum* (Pers. ex Wallr.)]
red belt fungus	*Fomes pinicola* (Schwartz ex Fr.) Cke.
red ring rot	*Fomes pini* [(Brot.) Fr.] Karst.
shoe string fungus	*Armillaria mellea* (Vahl ex Fr.) Kumm = [*Armillariella mellea* (Vahl ex Fr.) Karst.]
sirococcus shoot blight	*Sirococcus strobilinus* (Desm.)
soft spongy white rot	*Ganoderma oregonense* Murr.
white heart rot	*Fomes robustus* Karst.
white ring rot	*Poria albipellucida* Baxter [*Poria rivulosa* (Berk. & Curt.) Cke.]
white trunk rot	*Fomes hartigii* (Allesch.) Sacc. and Trav. [*Fomes robustus* Karst.]
yellow laminate root rot	*Poria weirii* (Murr.) Murr. = [*Phellinus weirii* (Murr.) Gilbertson]

Mammals, Birds, Fish

bear, black	*Ursus americanus* Pallas
bear, brown	*Ursus arctos horribilis* Ord.
beaver, bank	*Castor canadensis* Kuhl
beaver, mountain	*Aplodontia rufa* (Rafinesque)
deer, Columbian black-tailed	*Odocoileus hemionus columbianus* (Richardson)
deer, Sitka black-tailed	*Odocoileus hemionus sitkensis* Merriam
eagle, bald	*Haliaeetus leucocephalus alascánus* Townsend
elk, Roosevelt	*Cervus elaphus roosevelti* Merriam
goat, mountain	*Oreamnos americanus* (Blainville)
hare, snowshoe	*Lepus americanus* Erxleben
rabbit, brush	*Sylvilagus backmani* (Waterhouse)
salmon, coho	*Oncorhynchus kisutch* (Walbaum)
sapsucker, red-breasted	*Sphyrapicus varius ruber* (Gmelin)
squirrel, red	*Tamiasciurus hudsonicus* (Erxleben)
trout, cutthroat	*Salmo clarki* Richardson
wolf	*Canis lupus* Linnaeus

[1/] Nomenclature follows Shaw (1973).

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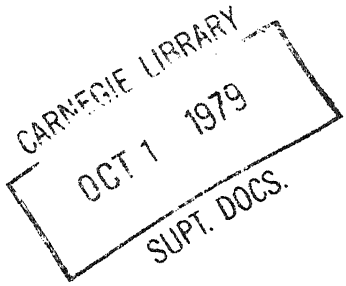

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